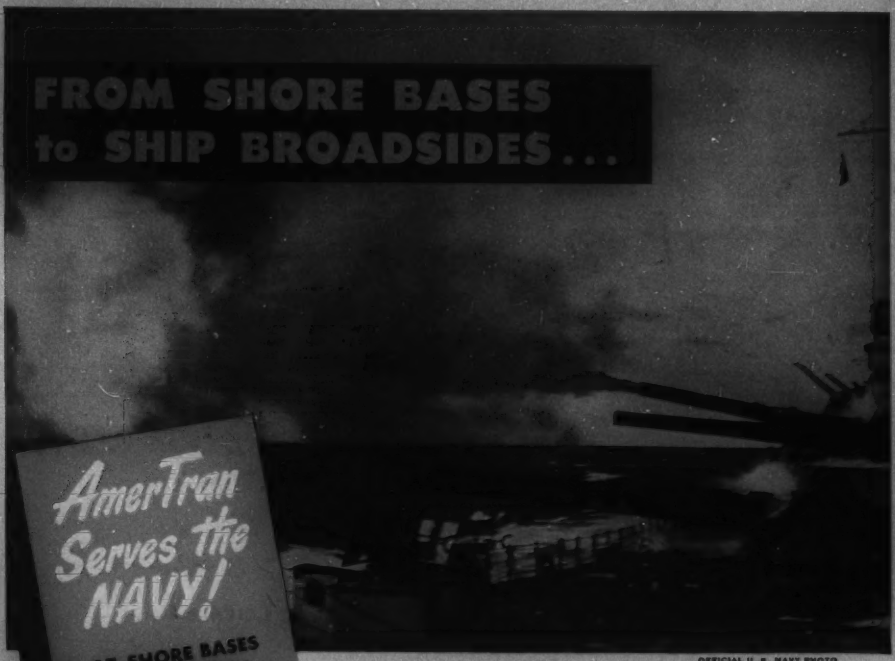
ELECTRICAL ENGINEERING

JULY 1943

FROM SHORE BASES to SHIP BROADSIDES...



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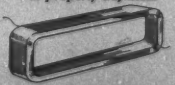
Typical Wire Service Problem

Field coil before winding machine was properly adjusted.



Field coil after winding machine was properly adjusted.

A Belden Wire Engineer was called in to check the winding operation, and after an inspection of the winding machine, pointed out the cause of the difficulty and recommended a few simple changes in the feeding of the wire. After the change was made, the field coils were easily removed from the winder head without twisting. Belden Wire Engineers will gladly help you with similar wartime wire problems at any time.

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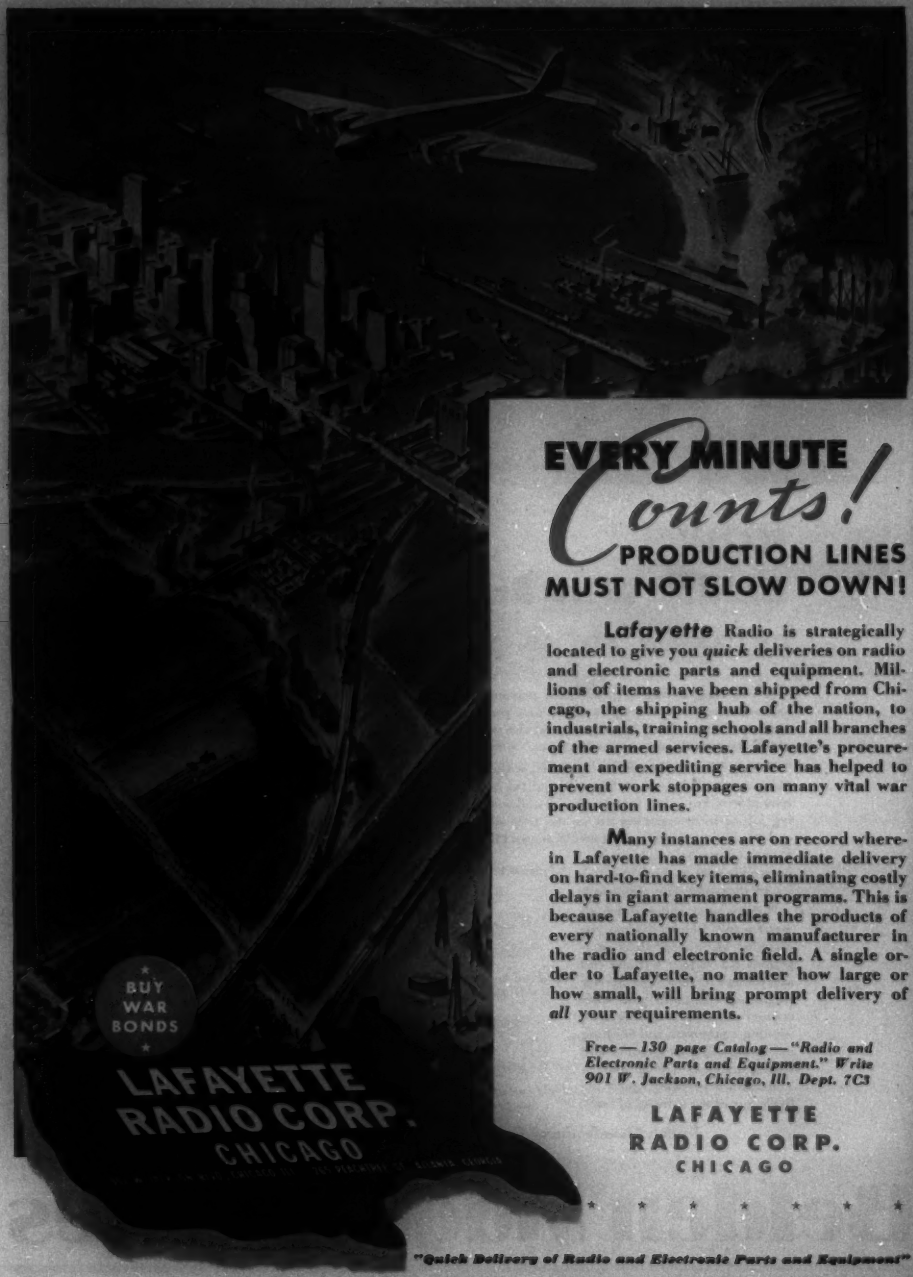
July 1943, Vol. 62, No. 7. Number of copies this issue 22,760



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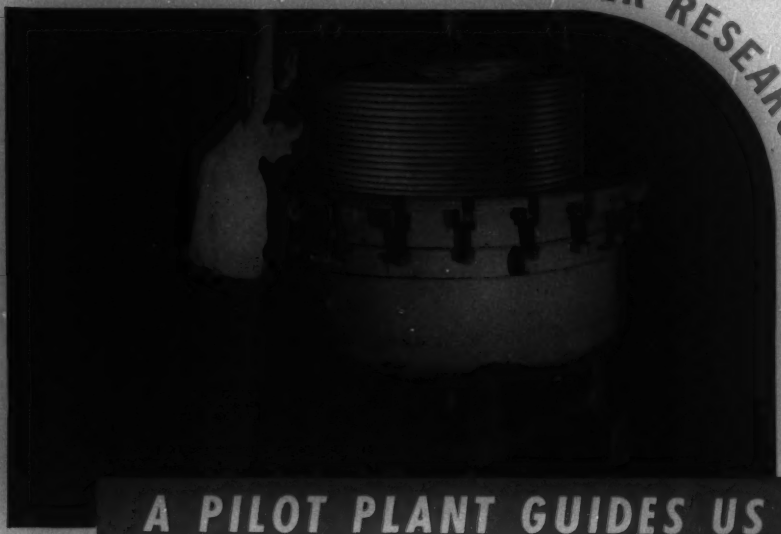

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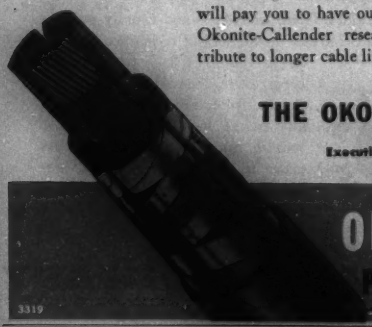

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Here at IRC we welcome—and usually solve—unusual problems in the field of resistance devices. And because IRC makes more types of resistance units, in more shapes, for more applications than any other manufacturer in the world, many leading engineers make it a point to seek our unbiased counsel. There is no obligation, of course.

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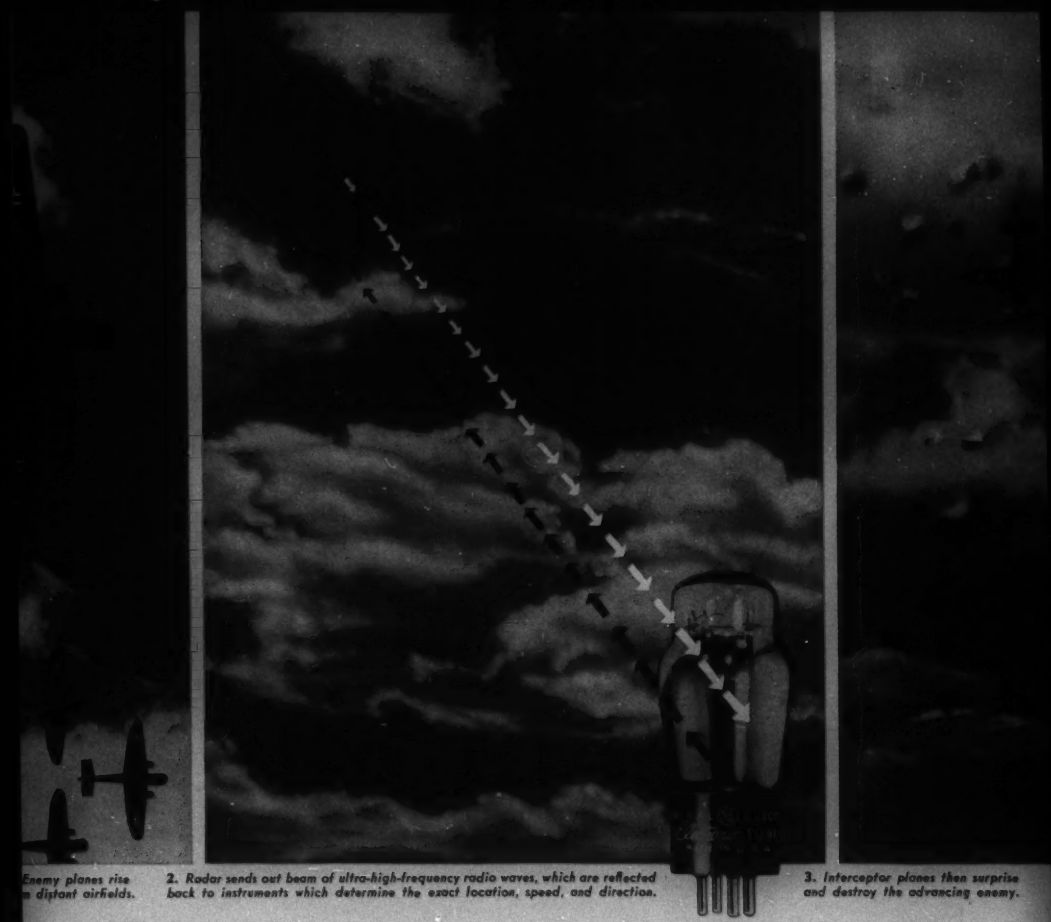

Enemy planes rise from distant airfields.

2. Radar sends out beam of ultra-high-frequency radio waves, which are reflected back to instruments which determine the exact location, speed, and direction.

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THE NEW YORK TIMES, MAY 16

This amazing electronic invention that locates distant planes and ships despite darkness and fog is a great co-operative achievement of Science and Industry.

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As early as the Twenties, G-E engineers and scientists were developing the kind of high-frequency tubes, circuits and apparatus that make Radar possible. Thus long before Pearl Harbor, G.E. was able to build

Post-war applications will be many. Radar will guard and guide the flight of great commercial transports. Planes will land blind. Transoceanic liners will slip safely into fog-bound harbors — all with Radar detection equipment.

In addition to Radar, General Electric is supplying to the Army, Navy, and Marines radio transmitters, antennae and receivers, carrier-current equipment, all kinds of electronic measurement equipment, and monitors. *Electronics Department, General Electric, Schenectady, N.Y.*

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GENERAL ELECTRIC

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RCA first developed the Beam Power Tube for the "Receiving" field, subsequently carrying this important development into the field of Transmitting Tubes.

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The Cover: Sighting of this three-inch antiaircraft gun of the 62d Coast Artillery defending New York against a simulated night air raid is done automatically, accurately, and instantly by an electrical control system

Official Signal Corps Photo

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VOLUME 62

NUMBER 7

Statements and opinions given in articles and papers appearing in *Electrical Engineering* are the expressions of contributors, for which the Institute assumes no responsibility. ¶ Correspondence is invited on all controversial matters.

Published Monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

HAROLD S. OSBORNE, President H. H. HENLINE, National Secretary

PUBLICATION COMMITTEE: Howard S. Phelps, *chairman*; C. E. Dean; F. Malcolm Farmer; H. H. Henline; K. B. McEachron; John Mills; A. G. Oehler; P. H. Pumphrey; H. H. Race; S. B. Williams

Electrical Engineering: Copyright 1943 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York, N. Y., by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

A Flag with 46,200 Stars

THE service flag of the Bell System had 46,200 stars on May 1. It has a lot more now. Telephone men and women are serving with the armed forces everywhere.

Those who are right in the middle of the fighting realize especially the importance of the telephone job back home.

"Tell the gang," their letters say, "to keep on plugging.

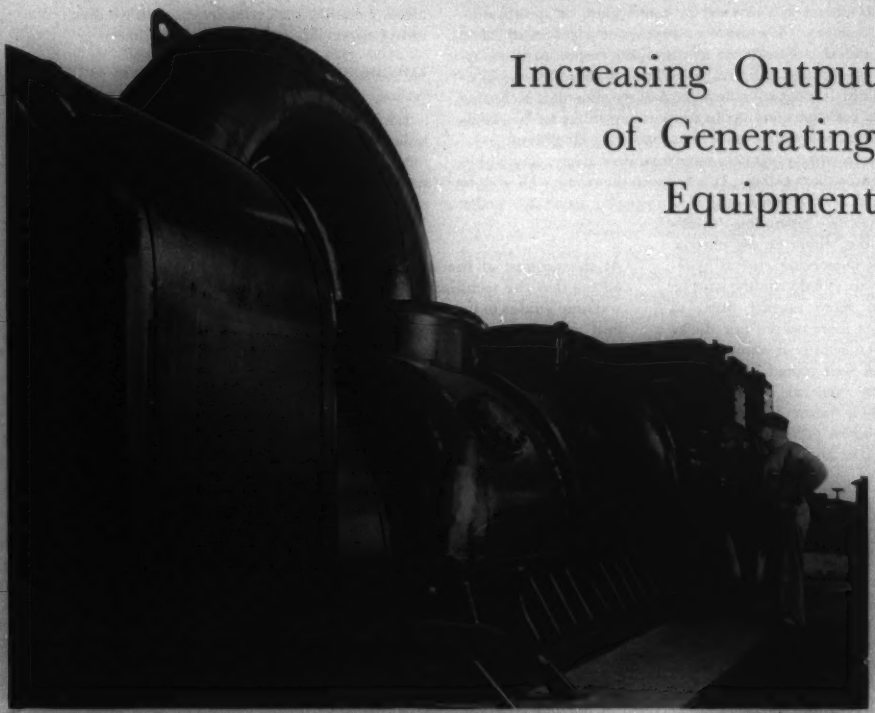
"We wouldn't have the stuff for fighting if the rest of the Bell System wasn't sticking to the job and pushing through the calls that get things done.

"Takes team-work to win a war — especially a big one like this."

BELL TELEPHONE SYSTEM

★ *Your continued help in making only vital calls to war-busy centers is more and more essential every day.*

Increasing Output of Generating Equipment



MOST systems are faced with the same general types of wartime problems. Many are attacking them in much the same manner. However, it is believed that the following compilation and discussion of various methods and practices being followed in meeting wartime problems, description of particularly novel or ingenious practices and methods, determination of practices being followed most widely, and more detailed consideration of particularly pertinent subjects such as loading of generators will be a useful contribution to the war effort. This approach allows a pooling of ideas which the industry as a whole can draw upon and check against in its efforts to increase output of present generating systems.

There appears to be a worth-while reservoir of generating capacity for emergency use that still can be tapped in many cases by:

1. Reducing reserve capacity.

2. Adopting short-time loadings for generators and prime movers to replace normal reserves.

3. Loading each individual machine to its maximum safe continuous capacity as determined by allowable generator temperature or other limiting feature.

4. Studying all electrical and mechanical features of plants to eliminate existing bottlenecks to increased capacity.

5. Reviewing of interconnection facilities and contracts to eliminate features that limit maximum benefits.

6. Permitting a justifiable reduction in service reliability.

7. Allowing frequency to drift downward a fraction of a cycle or voltage to be lowered if total capacity is not quite adequate for an emergency at time of peak load.

8. Increasing pressure in hydrogen-cooled generators.

9. Operating generators at higher than rated voltage if power factor of load is higher than rated.

10. Taking full advantage of class-*B* insulation where it is now operated with class-*A* temperature rise.

Manufacturers' and Operators' Responsibility. Some suggestions made in this report* involve operation under

*The Interim Report on Emergency Measures to Increase Output of Generating Equipment and Systems, sponsored by the AIEE power generation committee (A. C. Monteith, chairman 1942–43), was presented at the AIEE national technical meetings in New York, N. Y., January 25–29, 1943, and in Cleveland, Ohio, June 21–25, 1943; at the AIEE South West District technical meeting in Kansas City, Mo., April 28–30, 1943; and before the electrical equipment committee of the Edison Electric Institute. Copies of the complete report (43-93-ACO) are available at AIEE headquarters at 65 cents each.

conditions not covered by name plate or specification condition. The usual conception of a generator name plate is to identify the machine with respect to manufacturer and to indicate basic rating as fixed by specification. It does not guarantee that the generator is capable of safe operation up to temperature limits set by standards, irrespective of all other operating conditions.

In order to be safe, some operators always stay within name-plate rating. It is believed that those who wish to get a little more out of a particular generator under specific operating conditions, either for the purpose of conserving critical materials to help win the war, or in more normal times to get more output per dollar of generator investment, will be well repaid for studying the general problem and their particular generators and for taking responsibility as to how these generators are to be operated.

At the request of the AIEE standards committee that the technical committees prepare wartime guides to help the electrical industry find ways and means of getting more out of what it has, two subcommittees of the AIEE committee on power generation have made surveys of what has been done by manufacturers and operating companies to increase the output of generating equipment and systems. This article outlines the results of the work of these two subcommittees; it comprises the "Summary" of the complete report.† Like other guides in this series, this report is intended to be educational and in no way mandatory. At the end of the war emergency, these guides will be reconsidered, and either approved, revised for normal use, or rescinded.

While a name plate does not signify more than specified characteristics, it should be recognized that manufacturers must have some guide in designing a generator which will indicate probable conditions under which the generator will operate. Therefore, the manufacturer's desire to stay within name-plate rating should be appreciated as the only criterion of operation available on which to base the design.

In investigating occasional cases of generator failure, it is interesting to note that nearly every failure brings out some new point with regard to generator design and operation. The design engineers are specialists. If generators are to be operated above name-plate rating under specific conditions without damaging them unduly or aging their insulation, the designers' co-operation in fixing limits will minimize the responsibility taken by operators when operating at other than name-plate rating. The manufacturers have stated their willingness to consult with operators and give them their best judgment for particular machines in question. In presenting the manufacturers' material in this report, they have picked case examples to indicate possible gains by different methods of operating machines, not with the idea that specific figures in the report will be used to operate any machine, but rather to indicate what might be obtained from the different factors. They feel that each machine should be treated as a special case.

Loading machines beyond name-plate rating will decrease the life of the insulation. It appears desirable that various economic consequences should be recognized, including such considerations as winding replacements, depreciation reserves, and the like.

EMERGENCY MEASURES TO INCREASE OUTPUT OF GENERATING EQUIPMENT*

Large generating equipment is normally designed and built to meet definite ratings and performance requirements as covered by mutually agreed on purchasing specifications or contract conditions. Most modern large generating units have class-*B* insulation for both stator and rotor windings. Large water-wheel generators synchronous condensers, and frequency-changer sets usually have class-*A* temperature-rise guarantees and class-*B* windings. Turbine generators which inherently are restricted in rotor ampere-turn output have class-*B* temperature-rise guarantees for rotor windings and class-*A* guarantees for stator windings. It is obvious that past and present purchasing practice has been to obtain generating units of great reliability and long life. The name-plate rating of the generator unit is usually the contract rating or an adjusted rating determined from tests at the factory or in the field.

Normal life expectancy of specific generating unit must be considered as depending upon load carried, load cycle, and quality of maintenance provided. Any contemplated increase in generator output above its contract rating necessitates full realization that there is an unknown reduction in life of the windings at the higher rating.

In considering increased output the owner or user of a generating unit is faced with two somewhat conflicting points of view. The manufacturer's responsibility during the guarantee period is definitely associated with the contract or name-plate rating and the performance guarantee. After expiration of the guarantee period the unit is unquestionably the customer's property to be used as conditions warrant. From the user's point of view, it may be considered sound practice to operate the unit (*a*) up to its contract value of temperature guarantees, or (*b*) up to the temperature limit of insulation used and as recognized by the AIEE and ASA standards. These principles must be extended to include all items of the machine affected by temperature in addition to the field and stator windings.

* This section of the report was prepared by the subcommittee on emergency measures to increase output of generating equipment: C. M. Laffoon, *chairman*; S. H. Mortensen, Robert Treat.

† See footnote on preceding page.

Increasing Generator Output by Changing Generator Voltage. Some additional output can be obtained by taking advantage of the temperature margin that may exist in specific units. This may necessitate small changes in generated voltage and operation of each unit at the power factor most favorable for increased output.

A reasonable increase in generator voltage can be obtained without any increase in over-all flux of the unit by operating at higher power factors, which makes possible an increased output without increasing the stator current and without increasing appreciably iron losses under the higher load conditions.

Generators With Class-B Insulation and Class-A Temperature Guarantees. A machine with class-*B* insulation and class-*A* temperature guarantees can be operated continuously at loads which result in recognized class-*B* temperatures, provided its other characteristics are satisfactory at the increased rating. For machines of this class approximately 15 per cent increase in rating can be obtained with a reduction in life expectancy corresponding to the higher temperature.

Operation of Generators at Increased Output for Short Periods. Increased generator output at temperatures in excess of temperature limits recognized for the class of insulation and its application results in an appreciable decrease in life expectancy of the windings. This method of obtaining additional output for continuous or short-time loadings, with its resultant decrease in life expectancy of the insulation, may be justified economically under specific conditions.

In water-wheel generators and smaller turbine generators, field coils are comparatively free to move with change in temperature. While field insulation has to withstand a much lower voltage than armature windings, field windings are subjected to centrifugal forces, resulting from rotation, which put mechanical stresses on the insulating materials.

In large turbine-generator rotors, expansion and contraction are at least as important as total hot-spot temperature in determining insulation aging. A considerable part of the embedded length of the field copper may be considered as clamped to the wedges because of extremely high radial forces due to centrifugal loading. If the field windings are heated sufficiently while in this clamped condition, the conductor may be deformed plastically. A number of heating and cooling cycles may cause shrinkage of the rotor coils to the point where insulation failure may occur. Failures of this type are a function of temperature of the rotor as it comes up to speed, maximum temperature reached, and number of heating and cooling cycles to which the rotor is subjected.

In the stator winding, differential expansion results in relative movement between the outside of the insulation and the stator teeth, or it may cause internal slippage of the insulating material with the outside of the insulating wrapper more or less fixed with respect to the laminations. Since the end portions of the stator coils are anchored to fixed supports, expansion and contraction effects may result in either buckling or cracking the insulation.

Operation at Constant Temperature. Increased output can be and in some cases is being obtained by taking advantage of low ambient temperatures of the cooling medium. Although specification values of total temperatures are not exceeded, the life expectancy is decreased because of increased differential expansion and contraction of the winding copper and the surrounding iron.

Operation of Hydrogen-Cooled Generators at Increased Gas Pressures. In most cases, output of hydrogen-cooled generators can be increased approximately 15 per cent by increasing average pressures of the cooling gas from one-half pound gauge to 15 pounds gauge. Such increase in gas pressures may require changes in auxiliary equipment for supplying oil to shaft gland seals and for operation of the gas control.

Operating Practice for Reducing Hazards When Operating at Increased Ratings. Injurious effects of expansion and contraction due to starting and stopping conditions can be reduced by keeping the machine relatively hot during the shutdown period or preheating the field winding prior to starting. This can be accomplished by use of space heaters or by shutting off the cooling water to the gas coolers as soon as load is removed from the machine. Some improvement in life can also be obtained by regulating the flow of cooling water so that differential expansion can be kept more nearly constant for different ambient-temperature conditions. Increased loading of generators increases the desirability of careful inspection of both rotor and stator windings for evidence of distortion, cracks, and other forms of deterioration. Special precautions should be taken to keep the windings clean, loads balanced, temperature-indicating instruments checked, and readings taken on all detectors.

General Conditions. Since so many factors are involved in determining the available increase in output of large generating equipment, and any increase in loading must be checked carefully in relation to other associated main equipment, auxiliary apparatus, and the distribution system with its connected load, it is recommended that each case be checked with the respective suppliers. After obtaining and reviewing all essential data, the user and supplier should agree mutually on the rating capabilities of each particular unit, with full realization that the increase in output will result in a shorter life expectancy, and affect other important characteristics of the unit.

EMERGENCY MEASURES TO INCREASE OUTPUT OF GENERATING SYSTEMS*

Loading Generators by Temperature. There appears to be a general trend toward loading generators by temperature. Many systems report either that they have made

* This section of the report was prepared by the subcommittee on emergency measures to increase output of generating systems: R. P. Crippen, *chairman;* H. A. Dryar, A. J. Krupy, G. H. McDaniel, M. J. Steinberg.

temperature tests or calculations to determine how much their generator loads may exceed name-plate rating safely, or that they are operating according to temperature limits with temperature indicators for both stators and rotors instead of primarily by ammeter indications. The following conditions may permit continuous loading above name-plate rating:

1. Manufacturer's factor of safety larger than necessary to protect guarantees and meet operating contingencies such as load swings and small unbalance in phrase loading. This does not show in name-plate rating but may permit additional loading under proper conditions.

2. Load-carrying ability increased because ambient temperatures are less than specified maximum.

3. Kilowatt load capacity of generator increased because of power factor being higher than specified.

4. When adapting a standard design of generator to a specific operating condition, particularly in regard to power factor, it may be found that either raising or lowering terminal voltage may allow greater output in either kilowatts or kilovolt-amperes.

Additional factors which may permit loading above name-plate rating for short periods are:

1. When starting from light-load and low-temperature conditions, a generator can carry short-time loads in excess of normal capacity without exceeding normal temperatures, because it must absorb a considerable amount of heat before its temperature reaches a dangerous level.

2. In emergencies and for short-time peaks it may be more economical to operate a generator above its ordinary operating temperature, thereby incurring greater than normal rate of insulation aging for a short time, than to provide additional generating capacity for short-time loads.

Generators are important and costly machines; therefore due consideration should be given to a number of factors in arriving at maximum limits for either continuous or short-time operation above name-plate rating. The manufacturer's co-operation is desirable in studying individual generators for such operation. However, it seems desirable to suggest certain relatively conservative rules which it is believed will apply to most generators when loading them beyond their name-plate rating.

Rebuilding and Rehabilitation. Sometimes alterations can be made in generators on their auxiliary equipment to give added capacity. Cases have been found where recirculation of generator cooling air or water reduced capacity. One plant installed a cooling tower to reduce the high temperature of recirculated generator cooling water. In another instance increased capacity was obtained by installing a closed cooling system on a generator that had been discharging its ventilating air into the turbine room.

When it becomes necessary to reinsulate a generator, it may be advantageous to utilize a better grade of insulation to obtain greater capacity or longer insulation life. Where class-*A* insulation is replaced by class-*B* in a motor or generator, the capacity can be increased because of the increased permissible operating temperature. Also new insulation may require less space and therefore allow a larger copper cross section in the same slots.

Interconnected Operation. Principal benefits of interconnected operation have been arranged in accordance with the number of times the particular benefit was specifically mentioned in answers, as follows:

1. Continuity of service improved.
2. Maintenance schedule made more flexible.
3. Reduction in spinning reserve.
4. Diversity in loads of systems.
5. Replacement of high-cost steam energy.

Other benefits listed and finding appreciable support were:

6. Outlet for surplus hydroelectric energy.
7. Hydroelectric replacement transactions.
8. Higher load factor on efficient steam stations.
9. Reduction in fuel requirements.
10. Increased firm capacity of hydroelectric plants.

Interconnection may increase available capacity by decreasing spinning reserve requirements, by allowing steam plants to run at higher load factor with resultant storing of water at hydroelectric plants for carrying peak loads, and by whatever diversity there may be between the loads of interconnected systems.

Several systems with long interconnecting lines of 110 kv and 132 kv have had excellent results with automatic tie-line load-control equipment in decreasing magnitude of load swings on lines and thereby allowing increased loading without a corresponding increase in number of line tripouts because of steady-state stability limits being exceeded on load swings.

When systems are interconnected by relatively weak links, such as long single lines or frequency changers, application of automatic tie-line load-control equipment may result in a definite gain in transmission capacity.

Arrangements have been made in a number of instances for industrial customers having generating plants to operate in parallel and feed power back into the system, to carry their own load, or to carry reactive kilovolt-amperes. Other reported benefits from this type of operation are obtaining firm capacity, improved line regulation, improved service reliability in the immediate area, reduced peak demand, and reduced transmission losses.

Effect of System Voltage and Frequency on Load. Differences of opinion as to relative effectiveness of reduction in voltage as compared to reduction in frequency may very well be due to the different character of loads on different systems. Under proper conditions either or both methods may be effective in producing a certain percentage reduction in load.

With mixed types of loads it appears that total system load will usually be reduced by a slightly greater percentage than the percentage voltage reduction. Feeder

voltage regulators must be made inoperative, or they will counteract the reduction in system voltage.

The consensus is that reduction of either voltage or frequency to reduce system loading is practicable only for short-time emergencies.

Magnitude of permissible voltage reduction is limited to a value below which there is possibility of damaging equipment or stalling motors. Outage of generating equipment on some systems has allowed system voltage to fall as low as 85 per cent over the peak load for several days in succession without any apparent damage to equipment.

A definite schedule of step-by-step load curtailment appears desirable to meet the exigencies of present operation, with reduced reserves and the possibility of bombing. Reduction of voltage or frequency may be considered as the first step in such a schedule. A good example is the following answer received:

"Because of war hazards, we have a definite program of load curtailment in order to be prepared to hold on to our important military loads in case of loss of generating equipment or interconnection ties. We are able to make very definite curtailment in load by reduction of bus voltages by five per cent and by cutting back on feeder voltage regulators in substations a like amount. We are also able to get a considerable curtailment in load by cutting down the speed of street cars in the transportation system which we operate. These methods have actually been used in one case where we had a simultaneous outage of three major boiler units. Further methods of curtailment consist of actually getting customers to curtail their loads, and more drastic means in the nature of actual arbitrary circuit disconnections by the power company."

Power-Factor Correction. Power factor should be considered from the viewpoint of the whole system, beginning at customer's service switches and ending at the generating stations. Most companies attempt to generate reactive kilovolt-amperes in the reactive load area. To do this most effectively requires not only good system design but also good operation to keep power-factor correction in step with hour-to-hour changes in system reactive loading.

It is common practice to float hydroelectric generators on the line for power factor and voltage control. Good practice dictates that steam turbines shall not be loaded below certain values, generally in the neighborhood of 25 per cent of rating. Frequently this practice results in a decrease in over-all plant efficiency. One company reports that when turbine generators are floated on the line, cooling steam for the turbines is supplied from the main boilers through orificed by-passes around control valves. Another company is making tests on supplying cooling steam through by-passes around control valves but using steam at five pounds per square inch for station auxiliaries. A third company operates with the turbine blades in a vacuum.

Miscellaneous Methods of Releasing Capacity, Saving Losses, and Saving Critical Materials. Practice varies as to switching excess transformer capacity out of service during light-load periods. When both core losses and copper losses are considered, it does not appear that there will be ordinarily any advantage in switching transformers out of service if those remaining on the line will be loaded above name-plate rating.

Turning gears are used on a considerable number of large turbogenerators to equalize cooling of all parts of rotors and to allow machines to be brought up to speed and put on line more quickly than would be possible otherwise. Their performance appears to give general satisfaction. They are more important in reducing required spinning reserve on systems where steam generation is predominant than on systems with considerable hydroelectric generation, because on a hydroelectric system there is usually equipment which can be brought up to speed and put on the line in a very short time.

Daylight-saving time, 24-hour work by many industries, and dim-out regulation along the coasts have, in most cases, improved system load factor, thereby allowing greater kilowatt-hour generation without a corresponding increase in peak load. There may be some shifting of load to off-peak periods which can be effected if necessary, but many systems have daytime and nighttime peaks that are nearly equal. Shifting of load is more likely to be helpful on systems where steam generation is predominant and kilowatt-hour generation is usually limited by installed capacity than on systems where hydroelectric generation predominates, and total kilowatt-hour generation is limited by stream flow or pondage rather than by installed capacity.

Maintenance Schedules and Policies. Maintenance may be classified as breakdown, periodic, and preventive. Preventive maintenance is continually doing little critical maintenance jobs, in a scheduled and orderly manner, so that it is seldom necessary to do larger jobs. Generating units are generally in a good state of repair, because many companies, foreseeing that it would be difficult to do maintenance work when war loads became heavy, have done a more than normal amount of preventive maintenance in the last year or so.

The consensus is that load should not be curtailed unless it becomes necessary because of forced outage maintenance. There will apparently be no curtailment of load to meet schedules for preventive maintenance. Some answers indicate that maintenance schedules are made up a long time in advance and are adhered to very rigidly. One company stated that the preventive maintenance schedule was carried through at the expense of reducing operating reserves.

In most cases preventive maintenance schedules are not adhered to rigidly even though they were made up a year ahead of time. The period elapsing between scheduling of units has been lengthened in some cases, because of increased war loads.

Many companies have a rigid program of preventive maintenance and report that maintenance scheduling for a period of years has been adequate and therefore

has left power-plant equipment in a good state of repair. Therefore, with increased loads that have been experienced in the past year and are expected to be experienced in the near future, it has been unnecessary to increase preventive maintenance. However, several companies are doing extensive preventive maintenance to conserve critical materials and thereby avoid major trouble.

The most frequent cause of delays in maintenance, except possibly load conditions, has been delays in deliveries of material. Turbines have been returned to service after removing rows of bad buckets, and other temporary repairs have been made to equipment while delivery of material was awaited for permanent repairs. Deferring maintenance until additional capacity is available is used as a factor in shaping maintenance schedules.

No mention is made of delays in maintenance because of lack of personnel.

Personnel Problems. The personnel problem is one of the most serious situations faced by operating utilities. Trained men have been drafted or have volunteered for the armed services or have left for jobs with higher rates of pay. New personnel is difficult to obtain and is often below the caliber of new personnel in more normal times.

There has been considerable discussion about use of women in operating and maintenance departments, and considerable interest has been shown in obtaining the general point of view in this matter.

Ten companies report use of women as clerks in plants. Drafting work, meter reading, and use of wives of patrolmen and operators as operators are each mentioned. The following positions are filled by women in some cases: meter tester, chemist, telephone operator, janitor, chauffeur, time keeper, mechanic for boiler repairs.

One station in England which uses a large proportion of women on their operation and maintenance staff, including switchboard operators, cites the fact that at the start of hostilities they anticipated that use of women would probably be necessary and started training them early. This suggests that, if it is going to be necessary eventually to use women in operating jobs of responsibility, it would be well to start training them now in minor jobs, so that they can be advanced if necessary.

There is no trend toward installation of automatic equipment for release of trained personnel for other duties. However, some companies indicate that they place great reliance on such equipment, and its use in other places may be worthy of consideration.

The Conservation of Materials

H. S. OSBORNE
PRESIDENT AIEE

The conservation of critical materials—necessary to the successful prosecution of the war effort—is a problem which engineers particularly can help to solve, since most critical materials are used in operations under the direction of engineers.

IT is appropriate that the Institute and the other engineering societies should have made the subject of conservation of materials an important part of their programs during the past year. It is, as Mister Nelson and other authorities have said repeatedly, a continuing and most pressing problem and, furthermore, a problem to the solution of which everyone can contribute directly and effectively. Furthermore, it is a problem which engineers particularly can help solve. Critical materials, those used, both for war production and for essential civilian purposes, are, broadly speaking, consumed by processes under the direction of engineers.

It is of some interest to note at the start that critical materials are scarce because of limitations in productive capacity and not from any scarcity in their occurrence in nature. Aluminum is as plentiful as water—this is literally true—it is simply not so available. Considering everything material which is available to man—the crust of the earth, the seas and the atmosphere—one half of the total is oxygen and one fourth is silicon. If these two of the 92 elements are deducted, of the 25 per cent which is left more than half is aluminum, iron, and magnesium.

This fact may have led some of us at the beginning of the war to have a false sense of security—to feel that we are the great producers of the world, and therefore, must have an overwhelming proportion of the world's productive capacity of scarce materials. This was true at the beginning of the war. However, the Axis greatly improved their position by their conquests in Western Europe, Russia, and the Far East. The latest figures

Essential substance of an address delivered by President Osborne before many of the AIEE Sections during his term of office.

available, taking into account the effect of these conquests, show that the Axis then had 40 per cent of the world's productive capacity of iron and steel, 50 per cent of the capacity of aluminum and zinc, 60 per cent of the capacity of magnesium, 75 per cent of the tin, and 90 per cent of the rubber. This was, in part, offset by deficient capacities of some important things, particularly copper 20 per cent, and petroleum 7 per cent.

These figures are based on the latest data available, for the most part 1940 and 1941 and much has happened since then on both sides of the battle front. However, the figures are sufficient to make us realize that, by and large, we do not have an overwhelming superiority of productive capacity. In addition, the Axis has important resources not reflected in these figures. For years they had built up stock piles of the scarcest materials. Furthermore, they have systematically looted the occupied countries of the things which they needed, and these countries, of course, had vast quantities of metals and other materials in use for their ordinary domestic and industrial purposes. An Army authority remarked recently that so far the study of captured Axis war materials indicated they had not been obliged to make any compromise with quality for lack of raw materials.

Most of our scarcest materials are used for war purposes, and the armed forces are very alive to the problems of conservation. For example, the Ordnance Department of the Army has urged its manufacturers to make suggestions for changes in specifications or methods and has received thousands of suggestions which could be acted upon favorably. A recent letter from Major General Campbell, Chief of Ordnance, addressed to ordnance producers in American industry thanks them for their constructive suggestions of methods for increasing production; improving quality; and conserving materials, machines and man-hours; and closes with these emphatic words, "I cannot emphasize too strongly the fact that, unless means are devised to conserve critical materials, our production ceiling will soon be reached. This must not and will not happen. I know that I can count on you."

The tremendous results which have been obtained have been accomplished by literally thousands of changes. A broad consideration of the subject is best approached by the classification of these changes into different general methods of conservation.

Methods of Conserving Critical Materials

A. Making the greatest possible use of what we have:
   1. Increasing extent of use of existing facilities.
   2. Prolong life.
   3. Reuse of recovered materials.

B. Limiting of additions to and changes in facilities to those necessary for essential services. Similarly limiting production programs.

C. Making minimum use of critical materials in all construction and production:
   1. Substitution of less critical materials for more critical materials.
   2. Redesign to use less material.
   3. Limiting additions to facilities required for immediate needs only.
   4. Standardization.

D. Getting back into circulation materials which can be spared:
   1. Clean up and dispose of junk.
   2. Reduction of inventories.
   3. Taking materials out of working facilities.

Such a classification, similar to that which has been used by many of the Institute Sections in the consideration of this matter, accompanies this article. It is also similar to that used in a report prepared by the subcommittee on the conservation of materials published in the April 1943 issue of *Electrical Engineering*. That report gives various illustrations from within the electrical industries of the application of the different methods of conservation listed in the table.

The application of these methods of conservation involves a new approach on the part of engineers. Instead of projects being considered from the standpoint of economy of dollars, they must be considered from the standpoint of economy of materials; instead of projects being considered broadly from the standpoint of need or salability of services or products, consideration must be given to what is essential as a part of the war effort and to what can be done without.

Section A of the outline of methods refers to "Making the Greatest Possible Use of What We Have." This involves overloads of various types which normally would not be considered good engineering practice. It involves the use of maintenance and repair practices which normally would not be economical. It involves the development in many cases of improved methods of removal. For example, wire or cable which is to be reused must be taken down more carefully and by different methods than that which is to be junked.

Section B of the outline refers to "Limiting Additions to and Changes in Facilities to Those Necessary for Essential Services." This, of course, applies also to the production of products, as well as to the construction or modification of plant.

It is interesting to note, regarding the application of this method by public utilities, that under normal conditions they are under the legal obligation to give service to all comers without discrimination. This method of conservation involved discrimination between service demands which are considered essential and those which are not essential to the war effort. So the utilities needed help. They have received help in full measure in the form of numerous limitation orders of the War Production Board. As the utilities struggle with the headaches caused by these numerous orders, they will want always to bear in mind that the orders are a necessary part of the conservation program, enabling them to carry

out a form of conservation which otherwise would be beyond their power.

Item C of the outline and its subdivisions cover a group of methods of conservation which touch the work of all engineers. Consider, for example, subitem C-1, "Substitution of Less Critical Materials for More Critical Materials." That in itself is a large subject and a romantic one. It is also one of constant activity because of the changing relative scarcity of various materials. The WPB endeavors to keep people up to date on this matter by the periodic issuance of a "Material Substitutes and Supply List," giving current information regarding the relative scarcity of materials. Some of the things in which electrical men are most interested have for a long time remained in the scarcest group and, in fact, are starred as "most critical" among those in the group. These include copper, aluminum, tin, and zinc. It is to be anticipated that they will remain in this group as long as an all-out war-production program is called for.

Substitution problems are reflected in war production, as well as in production of civilian goods. A large Government-owned airplane plant, requiring 21,000 fluorescent-light fixtures, pioneered in the use of painted masonite for the reflectors, instead of steel. Airplane designers have worked on means for using plywood instead of aluminum for the pilot's seat. An interesting example of the severe requirements in the design of war materials, however, is the fact that, while 200 pounds is considered sufficient to allow for the weight of the pilot, the seat must be designed to withstand eight times this weight because of the accelerations involved.

Subitem C-2, "Redesign to Use Less Material," also touches the work of every engineer.

The specifications for Liberty ships called for 25,000 feet of highly protected power cable per ship. Engineers found it possible by careful design to reduce this length 10 per cent. A large magnesium plant, recently completed, included several thousand tons of copper in the form of bus bars and heavy feeder cables. By careful design and by having parts cut exactly to length in the shop rather than fitted at the job, 400 tons of copper were saved in building this one plant. These are illustrations of one type of application of this method—attention to the details of design in structures or any assembly of materials.

Another use of this method is in the application of improved processes; for example, one munition manufacturer recently reported that by applying the method of powder metallurgy to the manufacture of one complicated part 650 tons of a scarce alloy were saved.

Sometimes conservation is brought about by the application of a radically new device or a system. There is a good illustration of this in the telephone field. For a long time the telephone companies have made use of what are called carrier systems, that is, systems by which several conversations can be carried simultaneously over the same wires. Previously these had been applicable only on open wires on poles. Shortly before the war the research program of the telephone companies produced an improved system by means of which 12 conversations could be carried simultaneously on two pairs of 19-gauge wire in cable. This great extension in the application of carrier systems for the production of long-distance telephone circuits resulted in tremendous economies in the use of copper in the construction of large numbers of additional long-distance circuits required because of the war emergency.

The third subitem, "Limiting Additions to Those Facilities Required for Immediate Needs Only," needs no elaboration; it is simply designing plant to meet current needs rather than designing it as normally would be the case, to provide for expected future needs over an economic period, which is often a considerable number of years.

The last subitem is headed, "Standardization." Standardization has long been an important activity in the electrical industries, and the AIEE has, from the beginning, been a leader in the standardizing movement. There is great activity now in all industries, at the request of the war authorities, in advancing war standards designed to conserve materials and man power. In this work the American Standards Association plays an important part.

An interesting specific illustration is the standardization of the parts of the radio sets for the Army and Navy. A number of committees is very actively advancing standards covering a wide range of types of parts, capacitors, crystals, dynamometers, insulating materials, resistors, potentiometers, and so forth.

The whole standardizing program is credited by the WPB with having effected large savings in materials. A recent statement claimed the saving to date of 60,000 tons of steel and 17,000 tons of copper.

The last group of items in section D of the outline, refers to "Getting Back Into Circulation Materials Which Can Be Spared." Eighteen months ago in many industries saving was the order of the day. The war clouds were black on the horizon, and, to prepare for the time when materials could not be had, procedures were set in motion to save many things which ordinarily would be junked. But this saving of materials was for an emergency, and the point is that this is the emergency. This is the time to use up what we have, to decrease inventories as rapidly as practicable, and to be sure that we are not saving materials which, either because of their physical condition, or because of the unlikelihood of their being used during the war, ought to be junked if order to put back into circulation the critical materials which they contain.

One recent incident illustrates very well the present point of view in Washington regarding the need for getting materials into circulation. For some time the Treasury has been providing silver for new Government plants, where large amounts of electric current are involved, to be used instead of copper in the building of

new bus bars, feeder cables and heavy transformer windings. Between 15,000 and 20,000 tons of silver have been used in this way. The Institute was advised recently, however, that the Treasury had, in addition, about 16,000 tons of free silver not required for the construction of new Government plants which it was desired to put to work. The WPB obtained the approval of the Treasury to lend this silver to private industry to be placed in electrical installations as a substitute for existing copper in order that the existing copper thus released could be diverted to war purposes. This involves substituting silver for the copper now, replacing the copper and reclaiming the silver after the war, and guarding the silver for the duration of the war—expenses to be borne by the Treasury. The fact that this extreme move is being considered seriously is eloquent testimony of the need for additional copper. It is interesting to add that at the request of the WPB an AIEE committee was appointed to study with them the best means of making use of this silver in electrical installations, and the committee has made some constructive suggestions.

It has been pointed out that this problem of conservation is a problem for engineers. It is clear, however, that it is not a problem for engineers alone. It is a problem for everyone in the organization, particularly for every employee having to do with the use of materials. A part of the responsibility of the engineer, therefore, is to make sure that everyone in the organization realizes the importance of conservation and the methods of getting maximum results. A great deal has been done in training employees through articles in house organs, posters, exhibits, moving pictures, and so forth. There is no substitute in effectiveness, however, for a sustained showing of supervisory and managerial interest in the problem to insure that maximum results are obtained.

Conservation efforts are not limited to the employees of an organization. They apply also to the customers. Utilities—both power and communication—have long expressed this in their work with customers to help them to distribute the load and to avoid the use of unnecessary services. A great deal of help has been given by utilities to customers in the design of their own installations to use the minimum of materials.

For many organizations the biggest customer now is the armed forces. They, too, wish suggestions from suppliers as to methods of conservation, as the quotation from General Campbell's letter has already indicated.

One thing which is impressive in studying this matter is that small items should not be overlooked because they are small. For example, book matches are held together by a small staple of steel wire. It has recently been decided to shorten that wire one-quarter inch. By this means 100 tons of steel wire per year will be saved. As another illustration, it might be considered that it does not matter whether shoe eyelets are made of brass as they are so small. However, in 1941, 5,000 tons of brass were used for shoe eyelets.

Another point which strikes the student of this problem is the great effect of continued application to the problem. The results already achieved are certainly greater than any of us would have predicted a year or two ago. I do not think any utility man would have predicted then that in 18 months the use of copper by utilities could be reduced to ten per cent of its current rate without disrupting completely essential services, but this is what has been done in the past 18 months. While great progress has been made, it is evident that further progress must be made, since in many important ways the level of the war-production program is determined by the amounts of critical raw materials made available.

In conclusion, the problem of conservation of materials is a problem requiring the activity of all engineers and not something to be solved by groups of men in the armed forces and in the WPB. Beyond a certain point the conservation of materials requires a compromise between the saving of materials on the one hand and preserving the quality of essential services or products on the other hand. The problem is complicated and limited in extent of detail only by the detail of industrial and engineering processes. It is largely a technical problem and requires the application of the best technically trained brains in industry. We, who are associated with the electrical industry in various capacities, have the responsibility of using our imagination and our inventive genius in order to develop all the possibilities for conservation which there are and to keep those in authority completely informed so that the regulations of authority may at all times represent the best possible compromise in this difficult and essential matter.

Use of wood in place of steel in erecting this 110-kv substation structure on the system of the Public Service Company of Colorado saved 22,000 pounds of galvanized steel, and employed less labor which resulted in a saving of man power

Silver Anniversary of Symmetrical Components

C. L. Fortescue

In June 1918 Doctor C. L. Fortescue presented before the Institute the paper, "Method of Symmetrical Co-ordinates Applied to the Solution of Polyphase Networks." This paper has been recognized generally as having a far-reaching effect in the solution of unbalanced polyphase circuits. Since 25 years have now elapsed, the committee on power transmission and distribution believes that it is of interest and value to review the development and to consider the manner and extent of its effect on electrical engineering.

THE method of symmetrical components is basically a mathematical device for the practical solution of circuit problems. In many respects it bears the same relation to the solution of unbalance in polyphase a-c problems that the use of the complex number bears to the solution of single-phase and balanced polyphase problems. By the method of symmetrical components an unbalanced set of electrical quantities can be resolved into symmetrical systems of balanced quantities equal in number to the number of phases. Prior to the introduction of symmetrical components, the calculation of unbalanced networks was so laborious as to be impractical.

The title of Doctor Fortescue's paper included the term, "Symmetrical Co-ordinates." This term had its origin in the mathematical approach to the subject. Since then, however, the term symmetrical components, has come into general use, because it is more descriptive of the process to the engineer.

The beginning of the method of symmetrical components can be traced from concepts involving the use of positively and negatively rotating fields used in 1824 by Fresnel in connection with the study of polarized light and in 1892 by Ferraris and later by others in connection with the analysis of the single-phase induction motor. The concept of positively and negatively rotating fields was also used by E. F. W. Alexanderson in his phase balancer, which used an auxiliary machine, having a rotor that could be excited in the two axes, and a stator, connected for negative phase rotation, in series between the main machine and the system.

In 1912 L. G. Stokvis undertook the determination of the voltage regulation of the simple circuit consisting of a three-phase alternator subjected to unbalanced loads between line terminals. In solving this problem he used synchronous and inverse components which correspond in symmetrical components to the positive- and negative-sequence components. Stokvis did not have the concept of the zero-sequence component.

A method of resolving an arbitrary set of three vectors into residual, balanced three-phase, and single-phase components was developed by the California Joint Committee on Inductive Interference and used in their investigations as early as 1914. In this resolution the residual current is equal to three times the zero-sequence current of symmetrical components and, like the zero-sequence components, divides equally among the three phases. The single-phase current consists of a current flowing in a loop composed of two of the line wires.

The method of symmetrical components came to full fruition in the 1918 paper of Doctor Fortescue. In this paper the restrictions of previous work were surmounted, and a method of wide generality was developed, applicable to all kinds of circuit unbalances, to any num-

Sponsored by the AIEE committee on power transmission and distribution, Philip Sporn, *chairman*. Prepared by general systems subcommittee, C. F. Wagner, *chairman;* J. W. Butler, S. B. Crary, J. E. Hobson, E. K. Huntington, A. A. Johnson, A. A. Krooeberg, M. C. Miller, H. K. Sels, H. M. Trueblood.

ber of phases, and to all types of circuit elements such as alternators (neglecting saliency effects), transmission lines, and transformers. Before Fortescue, the advance toward the ultimate development of symmetrical components, as we know it today, had occurred by isolated contributions such as those of Fresnel, Ferraris, Alexanderson, and Stokvis. Fortescue developed the fundamental relations concerning unsymmetrical systems, not only for the conventional three-phase system, but for the generalized *n*-phase system, and established the treatment on a sound and rigorous basis. The range of his method is well illustrated by the great simplification it effects in the treatment of polyphase circuits and machines, which have to be dealt with in the majority of electrical problems in the power industry. Under normal conditions the electrical quantities involved are very nearly symmetrical; that is, the impedances in the different phases are substantially equal, as are also the couplings between phases. A unique advantage of symmetrical components for networks of this character is the absence of interaction between the currents and voltages of the different sequences. This is the most important feature that differentiates Fortescue's method from that of his predecessors. Ordinary unbalances resulting from unbalanced short circuits can be represented by merely connecting the otherwise independent networks of the different sequences together in definite relations at the point or points of unbalance. This simplification assumes added significance, because the generated electromotive forces in normal machines (excluding certain types of phase balancers) are of positive sequence only.

Originally the greatest value of Fortescue's paper was generally thought to lie in the analysis of unbalanced conditions pertaining to rotating machines. Several years later the need arose for practical methods of calculating unbalanced system short circuits and analyzing system stability. The enormous simplification resulting from the application of the method to these purposes was pointed out in several papers and articles which served also to popularize the method. Since then the principal use of symmetrical components has been for the solution of system problems rather than for the analysis of isolated rotating machines.

In the 25 years that have elapsed since the introduction of symmetrical components, the method has gathered power with use until it has become an indispensable tool for the analysis of unbalanced circuits, under both steady-state and transient conditions. The method has come into use in a wide variety of practical applications in the electrical engineering field and has had an important part in the theoretical developments of many of these fields.

Symmetrical components provide a basic method for the calculation of power-system fault currents for circuit-breaker and relay applications. Calculations for the ordinary application of these devices were so difficult as to make them in many cases impractical prior to the introduction of symmetrical components. The development and use of meters, instruments, and relays responsive to the various sequence currents and voltages, individually or in combination, was a natural result of Fortescue's discovery.

System stability is of importance, especially under transient conditions that arise from system faults and normally involve some type of unbalance. Symmetrical components have greatly facilitated the calculation of transient stability.

The calculation of system faults by the method of symmetrical components necessitated the determination of the sequence-impedance characteristics of rotating machines and transformers. Unbalanced operation of machines also led to the analysis of the heating of synchronous and induction machines in terms of the sequence quantities. Likewise, in solving problems involving cables and aerial lines, the general use of symmetrical components has led to the modification of the tables of conductor data to include the constants for the different sequences.

In connection with the inductive co-ordination of power and communication systems, symmetrical components have become important to the communication engineer. This has resulted from the fact that low-frequency voltages induced in communication systems are determined largely by ground currents in adjacent power systems, which are calculated most easily by the method of symmetrical components. The sequence properties of power-system harmonics are also of interest to the communication engineer.

It is a curious circumstance that little application of the method should have been found in the railway field, the unbalanced problems of which caused the search for an ultimate discovery of the method of symmetrical components. The reason for this is that few railway developments have made use of polyphase motors supplied from single-phase systems or vice versa.

The proceedings of the electrical engineering societies show how profoundly symmetrical components have affected technical papers. After a lapse of a few years, most authors writing on fault-current calculations, relay applications, machine performance, and so on, began to use concepts based on symmetrical components. Today the method is so generally accepted that it constitutes part of the college curriculum for electrical engineering students. Textbooks devoted to the subject are available in all the principal languages.

The original paper on symmetrical components by Doctor Fortescue is now universally recognized as having provided a new method of great practical importance for circuit calculations. It has become a mathematical tool of great practical value to the power-system engineer. Presentation of the method of symmetrical components by Doctor Fortescue in 1918—25 years ago—was certainly a milestone in the progress of the electrical industry.

Special Metals in the Electrical Industry

FRANZ R. HENSEL JAMES W. WIGGS

IN this brief review of specialized metals and alloys that are used in the various branches of the electrical industry we have attempted to survey these materials according to the type of applications and have listed them under the following general headings:

1. Resistor materials, including heating elements, thermocouples, and materials having controlled temperature coefficients of resistivity.
2. Bimetals, including both thermostatic bimetals and inlay and overlay metals.
3. Contact alloys.
4. Resistance welding electrodes.
5. Alloys with special magnetic characteristics.
6. Materials used in electronic tubes and X-ray tubes.
7. Special alloys for meters, such as pivot bearings and spring materials.
8. Miscellaneous applications.

RESISTOR MATERIALS

The standard resistor materials for heating elements are nickel-chromium alloys or nickel-chromium-iron alloys. In the straight nickel-chromium alloys, the analysis usually is 80 per cent nickel and 20 per cent chromium, whereas, in the nickel-chromium-iron alloys, the analysis is 60 per cent nickel, 15 per cent chromium, remainder iron. Real advancements have been made in recent years in the fabrication of these materials by employing special fabrication methods which include the use of specialized deoxidizers, such as zirconium, or materials from the second group of the periodic system. In Europe it is claimed that vacuum melting of these alloys greatly improves their life and ductility. Also, melting under hydrogen is said to give excellent products. In view of the present shortage of nickel, attention is drawn to a series of alloys which are iron-base alloys containing chromium and five to ten per cent aluminum. This class of alloys can be produced with a specific resistivity approximating that of standard nickel-chromium alloys. The materials have a higher melting point than nickel-chromium alloys and, therefore, can be used for higher temperature ranges as electric heating elements. These alloys have certain disadvantages, particularly low strength at high temperatures and low corrosion resistance if used in the form of fine wires. Some are also brittle at room temperature.

Recent advancements and current trends in the development of metals and alloys used in various branches of the electrical industry are of particular interest in view of present-day increased demands on the industry. Advantages and disadvantages of these metals and alloys for the various uses to which they are put are considered in this article.

For work at very high temperatures pure molybdenum is used. In this case it is necessary to use a protective atmosphere, such as hydrogen. It is claimed that special cracked gases may be used also; however, there exists the danger that molybdenum may be carburized and thereby embrittled. In recent years a molybdenum heating element for operation in air has been introduced. In this case the molybdenum is covered by a special refractory coating, and beryllium oxide is used as the layer next to the pure molybdenum. In addition to pure molybdenum it is also possible to use molybdenum-tungsten alloys for heating elements; however, the actual use of such alloys is very limited.

A new series of alloys has been announced which is supposed to produce extremely high values of resistivity of the order of 200 microhms per cubic centimeter. These are manganese-base alloys containing over 50 per cent manganese, the remainder being nickel and copper. These alloys are not intended for heating elements, but are planned primarily for use in various branches of the electrical industry as fixed or variable resistors. It appears that until the present these materials have been used to a limited extent only because of manufacturing difficulties. Some of them can be produced with controlled temperature coefficients of resistivity, depending upon the composition and heat treatment. Some are comparable to manganin and are characterized by having a low thermoelectric force versus copper, a property of importance in the construction of meters of high sensitivity.

A number of silver base alloys have also been developed recently, such as silver-manganese-tin alloys: 80 per cent silver, 17 per cent manganese, 3 per cent tin. Here again the temperature coefficient varies with the composition and heat treatment. Alloys of this type approach a zero temperature coefficient over a range of 0–200 degrees centigrade, and, for alloys containing ten per cent manganese, ten per cent tin, and the remainder silver, it is possible to produce a negative temperature coefficient which is desirable for compensating resistances.

Essential substance of an address presented at the symposium on rare and precious metals of the annual fall meeting of the American Institute of Mining and Metallurgical Engineers, Cleveland, Ohio, October 13, 1942.

Franz R. Hensel, a member of American Institute of Mining and Metallurgical Engineers, is consulting engineer with P. R. Mallory and Company, Inc., Indianapolis, Ind.

Alloys of palladium and silver, containing about 56 per cent palladium, have a temperature coefficient lower than manganin, possess excellent resistance to tarnishing, and have good electrical contact characteristics.

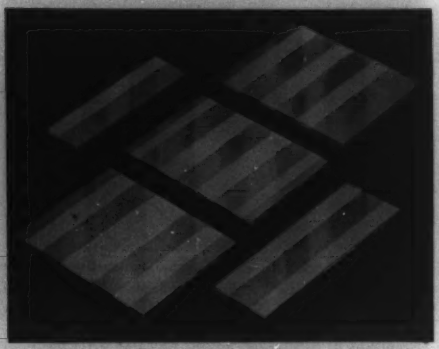


Figure 1. Inlay metal slabs faced with fine silver

These properties fit them for instrument application, particularly when sliding contacts are involved.

Thermocouples. In the field of thermocouples, the standard combinations such as platinum versus platinum-rhodium, chromel-alumel, iron-constantan and copper-constantan, are still used extensively. A newer-type thermocouple which has been used in recent years consists of nickel versus nickel-molybdenum. The advantage of this combination apparently consists in its stability in reducing atmospheres of the cracked hydrocarbon-air type. It is useful to about 1,200 degrees centigrade in such atmospheres.

In addition, other thermocouple combinations for high temperatures have been suggested, such as tungsten versus molybdenum and silicon carbide versus graphite. The former combination has been used in steel-melting practice with a protection tube. It is characterized by a rather low thermoelectric force and is therefore suitable only for high-temperature measurements.

BIMETALS

In the field of thermostatic bimetals, the standard alloys still seem to be useful for the majority of applications. The standard combinations are Invar on brass, austenitic steels versus Invar or austenitic steels versus 42 per cent nickel steel. Recently a high-manganese alloy, containing about 75 per cent manganese, 15 per cent nickel, and 10 per cent copper, has been suggested as a material for the high-expansion side of a thermostatic bimetal.

In addition to bimetals, recent needs have also brought about the manufacture of trimetals. In many cases it was necessary to improve the current-carrying capacity of thermostatic bimetals, and a layer of cadmium-copper between Invar and brass has solved this problem. Thermostatic bimetals have also been suggested where the low-expansion side consists of molybdenum, however; such specialized combinations are used only in very rare instances.

The study of alloys having a low coefficient of expansion has resulted in certain new materials of this type. Platinum alloys containing between 40 and 50 per cent iron, when properly heat treated, have a negative coefficient of thermal expansion over the range of 20–70 degrees centigrade. Attempts have been made to pro-

Table I. Resistor Materials Including Alloys for Thermocouples and Alloys Having Low Temperature-Resistance Coefficients

Name	Iron	Chromium	Nickel	Cobalt	Aluminum or Carbon	Resistivity	Ultimate Tensile Strength (Pounds Per Square Inch)	Melting Point (Degrees Centigrade)
Resistor Alloys								
Nichrome IV		20	80			108 microhms/cm³ 650 ohms/mil ft	110,000	1,320
Nichrome	25	15	60		0.12 C	112 microhms/cm³	100,000	1,350
Chromax castings	50	15	35				60,000	1,480
Number 193 alloy	68	2	30			91.3 microhms/cm³	80,000	Low temperature
Kanthal	67	25		3	5 Al	Approximately 810 ohms/mil ft		
Alcross	70	20			5 Al	800 ohms/mil ft		
Ohmax	75				10 Al	1,000 ohms/mil ft		
Alchrome 3	84	14			3 Al			
Thermocouple Alloys and Combinations								
Constantan—45 per cent Ni, 55 per cent Cu						48.8	135,000 to 63,000	1,210
Pt versus pt—10 Rh						Good for 2,800 F continuous or 3,000 F maximum		
Pt versus pt—13 Rh						Good for 2,800 F continuous or 3,000 F maximum		
Chromel versus Alumel						Good for 2,400 F maximum (calibration changes in reducing gases)		
Iron-Constantan						Good for 1,400 F continuous		
Copper-Constantan						Good for 700 F continuous or 1,000 F maximum		
Alloys of Low Temperature-Resistance Coefficient								
Invar	63.5		36.5			0.88×10⁻³ per degree centigrade, 66.4 microhms/cm³	72,500	
Super-Nivar	64		31		.5 Co	0×10⁻³	Hot rolled	
Kovar and Fernico	54		28		.18 Co			
Ferrichrome	37	8	30		.25 Co			
Elinvar	52	12	36		Low-coefficient elastic modulus			

duce materials having low coefficients of expansion combined with high elastic properties, such as Invar with the addition of beryllium to make the alloys susceptible to heat treatment. It is reported that Invar with one per cent beryllium has a Brinell hardness of 365 after

Figure 2. Typical platinum- and platinum-alloy-faced contacts

aging at 932 degrees Fahrenheit for one hour. Also, a stainless-type Invar has been developed, consisting of cobalt, iron, and chromium, and the maximum properties have been found with 54 per cent cobalt, 37 per cent iron, 9 per cent chromium.

Alloys having low temperature coefficients of expansion are used extensively for glass-sealing purposes, and in this case it is necessary to match the alloy with the glass into which it is to be sealed. A material used extensively for this purpose is an iron-nickel-cobalt alloy, containing about 54 per cent iron, 18 per cent cobalt, and 28 per cent nickel, which has a higher coefficient than Invar, but also a higher inflection point. In addition to these alloys, there are quite a number of chrome-iron alloys, nickel-iron-cobalt-chromium alloys, and similar compositions which are used for specific purposes.

In the field of overlay and inlay metals, advances have been made in bonding such materials as silver to steel, silver to copper-base alloys, copper to steel, and copper alloys to steel. A development which has been necessitated by the shortage of material is the fabrication of commutator segments of steel with a silver facing. It is quite possible that this development will result in a real improvement, because the strength of the steel will permit higher speeds of rotation without causing yielding and deformation of the commutator segments.

In connection with commutators, attention might also be called to the development of new brush materials, such as silver graphite working against a copper commutator: for example, in heavy d-c generators. It was found that with this combination a much lower voltage drop could be maintained, particularly when the polarity of the brush was positive with respect to the commutator.

Unquestionably the work on clad metals will be extended considerably as a result of the shortage of strategic materials. For instance, the use of silver-clad steel wire and silver-clad steel strips for current-carrying purposes has been suggested, and materials of this type are actually being produced.

CONTACT ALLOYS

The development of new contact alloys has been quite rapid, both new precious-metal alloys and composite metals. The use of platinum and iridium is restricted today almost exclusively to electrical purposes, such as make-and-break or sliding contacts. The platinum-ruthenium alloys have replaced to a certain extent the platinum-iridium alloys; however, the latter are still used for a large number of applications, particularly magneto contacts. Palladium and its alloys, and silver, gold, platinum, and other metals have found specialized uses in relays.

Composite metal compositions, such as Elkonites which are a combination of precious metals and refractory metals and their compounds, are used extensively for current-carrying and arcing contacts. New developments have resulted in materials with high arcing resistance and decreased contact drop. Metal combinations, such as silver and graphite, silver and nickel, and silver and cadmium oxide, have found use in certain circuit-breaker applications.

The field of heavier-duty aircraft relays has required the development of specialized contact materials for d-c applications of medium voltage and high current which will stand up when operated at low temperatures and reduced pressures. The construction of the relay and its electrical requirements also necessitate the mounting of these contacts on high-strength high-conductivity copper alloys, such as copper-cadmium alloys, copper-chromium alloys, and copper alloys hardened with special intermetallic compounds such as nickel silicides, cobalt, and nickel beryllides.

Improvements have also been made in copper-base contact alloys, such as contactor contacts, by such addi-

Figure 3. Solid rivet-type contacts of palladium alloy used in automobile voltage regulators

tions as selenium, lead, and tellurium. Materials of this class have less tendency to stick or weld together when making large currents. A contactor contact material, containing substantial amounts of cadmium and hardened by cobalt silicide, has found large application in

Figure 4. Elkonite-faced arcing tips for heavy-duty circuit-interrupting equipment

the form of contacts for timing equipment in resistance-welding machines.

RESISTANCE-WELDING ELECTRODES

For spot welding and seam welding the electrode materials, as well as the structural parts of resistance-welding machines such as arms and holders, are being fabricated from special age-hardened high-conductivity high-strength alloys: for example, copper-chromium alloys or copper alloys hardened with intermetallic compounds, such as silicides, beryllides, and phosphides. Advances have been made in producing sound copper-chromium castings by the utilization of lithium. Copper-base alloys containing nickel-silicide have been improved by the addition of zirconium. Such nickel-silicon-zirconium bronzes may represent an ideal substitute for certain beryllium-bearing copper alloys in view of the present shortage of beryllium.

The development of composite metal compacts such as Elkonites has resulted in materials having very high strength, combined with high hardness and conductivity. This progress has been made possible by utilizing age hardening. It is possible today to produce materials with a 50 Rockwell *C* hardness and more than 20 per cent electrical conductivity. It is to be expected that additional uses will be found for such materials, in view of their great wear resistance, both mechanical and electrical, and also because of the low contact drop that can be maintained. This type of material is used extensively for hot upsetting purposes in the present war-production program.

MAGNETIC MATERIALS

In addition to the improvement of the standard permanent-magnet steels, considerable progress has been made with the aluminum-nickel-iron magnet materials made either in the form of castings or by powder metallurgy. The addition of elements such as cobalt, titanium, and copper has resulted in improved magnetic properties. With sintered magnets, the addition of metal hydrides was found to be of advantage. The nickel-titanium-cobalt-iron magnet materials were found to be difficult to produce and are not yet in active use.

Oxide-powder magnets have advantages such as high specific resistivity and low density. The oxide-powder magnets consist of mixtures of magnetite, ferric oxide, and cobaltic oxide, and they are magnetized during cooling, from about 500 degrees centigrade.

Copper-base permanent-magnet materials have been developed, containing about 60 per cent copper, and the remainder nickel, cobalt, and iron. Such materials have a coercive force of 500 oersted and a remanence of about 3,000 gausses. The material can be heat treated but, even in this condition, it is quite ductile and lends itself to forming operations which are impossible with other permanent-magnetic materials.

High coercive forces also have been found in platinum-iron alloys, consisting of 50 atomic per cent iron, which corresponds to about 22.2 per cent iron by weight. It is possible to obtain a coercive force of 1,500 oersteds with a residual induction of 5,800 gausses. Similar properties are obtained with platinum-cobalt alloys containing 50 atomic per cent of cobalt, which corresponds to 23.3 per cent cobalt by weight. With platinum-cobalt it is possible to obtain coercive forces up to 3,700 oersteds. In both alloys the heat treatment is quite critical.

High coercive forces also may be obtained with the Potter alloy which is a silver-base material containing 87 per cent silver, 8.8 per cent manganese, and 4.2 per cent aluminum. This material is similar to the Heusler alloys, except that silver is substituted for copper.

In the production of magnetically soft materials such as pure iron, iron-silicon alloys, iron-aluminum alloys, and iron-nickel alloys, improvements have been made by the addition of smaller percentages of such metals as molybdenum, chromium, and copper, and also by new manufacturing methods based on special annealing and rolling techniques. The field of application for magnetically soft materials is quite extensive, and special compositions have been developed for applications where

Table II. Thermostatic Bimetals

Number	Composition		Useful Range (Degrees Centigrade)
	High Expansion	Low Expansion	
1	Iron, 27 nickel, 5 molybdenum	Invar (36 nickel, iron)	25–190
2	Iron, 27 nickel, 5 molybdenum	42 nickel, iron	60–500*
3	Nickel	Invar	60–190
4	Nickel	42 nickel, iron	20–350
5	42 nickel, 5 molybdenum, iron	42 nickel, iron	130–400
6	42 nickel, iron	Invar	250–340
7		Platinum, 45–55 iron	
8		Invar + 1 per cent beryllium	Increased elastic properties

* Inflection point near 300 degrees centigrade.

high permeability is required at low induction, or where a high saturation limit is required at high field strength, or where a combination of high permeability with a certain specific electrical resistivity is required.

Mention also might be made of the 30 per cent nickel-iron alloy and Permalloy containing considerable molybdenum, where changes in permeability with temperature are required to compensate for temperature errors. Further in this direction, alloys have been developed which lend themselves readily to production from metal powders with additional agents such as tin and phosphorus. Powdered alloys of this type are used for specialized iron cores. In most cases the material which is used for iron cores is relatively pure fine-grained carbonyl iron of a mesh size of several microns (2–7), having well-insulated iron particles. This type of iron core is used for high-frequency applications where it is necessary to obtain the greatest possible increase in inductance with a minimum amount of energy loss due to eddy currents and hysteresis.

MATERIALS FOR ELECTRONIC TUBES, X-RAY TUBES, LAMPS

In the construction of electronic tubes refractory materials, such as tungsten, molybdenum, and tantalum, are used extensively. Tungsten is used for lead-in wires, heating elements in vacuum tubes, electrode supports, anodes, rectifier-tube cathodes, and anticathodes in X-ray tubes. Other varieties of tungsten used are thoriated tungsten, containing 0.7 per cent or $1^1/_2$ per cent of thorium, for such applications as glow cathodes.

A large amount of tungsten is used for filament wire or as electrode tips in fluorescent-lighting tubes.

Table IIA. · Alloys for Sealing Into Glass

	Expansion Coefficient	Thermal Conductivity (Cal/Cm. Sec Grad)	Specific Resistivity (Mm²/M)	Glass (Corning)
Platinum	90.7×10⁻⁷ (25–100 C.)	0.167	0.108	G-1 and G-5
47½ Ni, 50 Fe, 1 Cr, 1 Mn	89×10⁻⁷	0.038	0.45	G-1 and G-5
Platinite 48 Ni, 52 Fe, 0.15 C	90×10⁻⁷	0.038	0.45	G-1 and G-5
Platinum-clad wire Pt on 48 Ni, 51 Fe	90 × 10⁻⁷			G-1 and G-5
Copper-clad wire Cu on 42 Ni, 58 Fe	Radial 80–100×10⁻⁷, Axial 61–65×10⁻⁷	0.4	0.04–0.06	G-1 and G-5
Borax coated 25–30 Cr, Fe remainder	95–100×10⁻⁷ (20–100 C.)	0.05	0.5	G-1, G-5, G-6, G-8
EMK 71 Fe, 10 Mo, 19 Co, 0.8 Si	90–95×10⁻⁷	0.05	0.33–0.37	G-1, G-5
Fernichrome 37 Fe, 30 Ni, 25 Co, 8 Cr	92×10⁻⁷			G-5
Wonico 80 W, 13 Ni, 5 Co	55×10⁻⁷		0.13	Osram Na hard glass
Tungsten	40–45×10⁻⁷	0.38	0.06	Uranium Nones
Molybdenum	53–55×10⁻⁷	0.35	0.06	G-71 G 705 AO
Kovar; Fernico Ni 28, Co 18, C 0.1, Fe	47 450 C. 56 500 C.	0.09	0.27	G 705 AJ G-71; G 705 AO

Molybdenum has a combination of high strength, high melting point, and ductility and, therefore, is used for grid supports, grids, anodes, and cathodes.

Tantalum is employed for its "getter" properties in electronic tubes. Tantalum can be readily degassed, a property of importance in this application. In addition to tantalum, certain tantalum-tungsten alloys are employed in tube construction.

Materials used for cathodes in photocells are caesium, rubidium, potassium, and selenium. In this connection caesium, rubidium, and potassium show a quicker electric response to incident light than selenium does. However, it is necessary to impress a small voltage across the cells containing caesium, rubidium, and potassium and, in most uses, to amplify the small currents they generate when illuminated. Selenium has the property of generating its own voltage when light strikes it and furnishes current which is of rather larger magnitude than that supplied by caesium, rubidium, or potassium.

Selenium for this use, as well as for use in rectifiers, must be of high purity, about 99.85 per cent. Its conductivity may be increased by incorporation of controlled amounts of certain selenides, and the conductivity is increased further by a carefully controlled annealing from near the metal's melting point. In this connection, some recent experimental results have been published on the subject of a photoelectric combination of cuprous oxide on copper where the oxide layer has been electrolytically deposited.

Sodium is used for sodium vapor lamps and, in the form of an amalgam, for liquid cathodes in tube rectifiers.

Zirconium-coated molybdenum is used as a substitute for tantalum. The zirconium coating is produced either by electroplating or by spraying onto the plates a paste containing metallic zirconium or zirconium hydride.

In Europe ductile zirconium has been used as a sub-

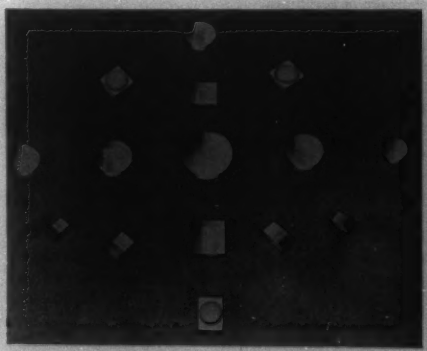


Figure 5. Silver-tungsten parts for direct-resistance brazing into contact assemblies

Figure 6. Typical contacts springs made of copper-cadmium, copper-chromium, and other copper alloys

Table III. Alloys With Special Magnetic Properties—Magnetically Soft Alloys*

Name	Composition
Hipersil	Si steel—controlled grain orientation High permeability and one-third more flux capacity than standard Si-steel
Hydrogen-iron	0.005 per cent C, 0.028 per cent Mn, all others 0.003 per cent or less
High Permeability at Low Induction	
Permalloy	30–90 per cent Nickel, remainder Fe ± Cr or Mo 78½ per cent Ni best. Heat treat
Mumetal	76 per cent Ni, 6 per cent Cu, 1.5 per cent Cr, Fe remainder
1,040 alloy	72 per cent Ni, 14 per cent Cu, 3 per cent Mo
High Permeability for Higher Field Strength	
Hypernik Nicaloi	45–50 per cent Ni, remainder Fe
Megaperm	65 per cent Ni, 10 per cent Mn, remainder Fe
Moderately High Permeability With High Electrical Resistance	
Rhometal	40–45 per cent Ni, 5 per cent Cr, 3 per cent Si
Constant Permeability Over Range of Flux Densities	
Perminvar	20–75 per cent Ni, 5–40 per cent Co, ± Mo, Heat treat
Conpernik, and so forth	40–55 per cent Ni—Heat treat
Isoperm	36–50 per cent Ni, 9–15 per cent Cu } Precipitation types
Isoperm	40–60 per cent Ni, 3– 4 per cent Al }
Compensator Types (High Temperature Coefficient of Permeability)	
	29–32.5 per cent Ni, remainder Fe; Mn, Cr, Si 70 per cent Ni, 30 per cent Cu; Fe or Mn plus Si

* See American Society of Metals *Handbook*.

stitute for molybdenum in tube construction because of its excellent "getter" properties. Base metals extensively used in tube construction are nickel and nickel-base alloys which have high strength at elevated temperatures: for example, a material which is age hardened by means of the addition of titanium, special pure irons, such as gas-free Svea iron, or sintered iron and certain copper alloys.

Mercury is used extensively in rectifiers as a liquid cathode. High-purity mercury must be used to prevent reignition.

Pure beryllium is used in X-ray apparatus for X-ray windows. Recent work has shown that a small addition of titanium is very helpful in producing sound and dense beryllium.

Consideration has been givento the use of gallium as a substitute for mercury for cathodes in rectifiers.

Metals characterized by special thermionic properties are nickel alloys containing barium. Recently it has been reported that increased ionization of spark gaps, and hence lower sparking voltage, can be obtained by incorporating polonium into nickel alloys. However, the usual oxide cathode used in radio tubes consists of a nickel core coated with a mixture of barium and strontium oxides and contains a trace of elemental barium developed during the activation process. The important use for such materials, however, is as electrodes for spark plugs where it is necessary to decrease the sparking voltage and maintain it at a constant level.

SPECIAL ALLOYS FOR METERS

In meters it is important to have bearings which have high wear and corrosion resistance. Formerly, precious stones, such as sapphires, were used extensively for this purpose, although certain glasses are now finding some use as emergency substitutes. In recent years, osmium-base materials which are hardened further by the addition of other platinum group metals have proved to be excellent substitutes. These osmium-base alloys are made either by melting or sintering. The alloys are extremely hard and very noble. In some cases nickel or cobalt may be added advantageously to these materials.

Alloys of similar compositions are used for long-life phonograph needles and pen-point alloys, and alloys

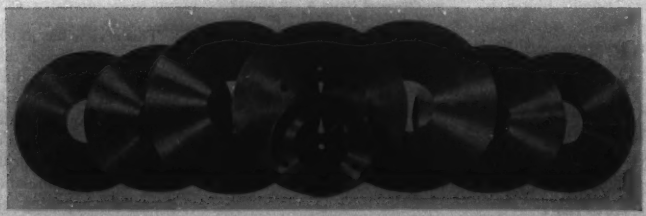


Figure 7. Resistance-welding electrodes (seam-welding rings and disks) made of copper-chromium alloy

Table IIIA. Permanent Magnet Materials*

Type	Composition
Magnet Steels	
C-Mn	0.6 C, 0.8 Mn
Cr	0.6–1.0 C, 0.2–0.4 Mn, 0.9–6.0 Cr
W	0.7 C, 0.3 Mn, 0.2 Cr, 5.5 W
Co	0.9 C, 0.35 Mn, 4.75 Cr, 1.25 W, 8.5 Co
Cr-Mo	.4 Cr, 0.35 Mo
Cr-W	0.5 Cr, 6 W
Cr-Co	.9 Cr, 16 Co, 1.3 Mo
Co-W	2–5 Cr, 17 Co, 8.75 W
Precipitation Hardening Types	
Fe-Ni-Al	24–30 Ni, 9–13 Al, Fe
Fe-Ni-Al-Co	24–30 Ni, 9–13 Al, 5–10 Co, Fe
Fe-Ni-Co-Ti	10–25 Ni, 15–30 Co, 8–25 Ti, Fe
Fe-Co-Mo	12 Co, 16 Mo, Fe remainder
Fe-Co-V	36–62 Co, 6–16 V, 30–52 Fe (Vicalloy)
Special	
Heusler type	65 Cu, 20 Mn, 13 Al, 1 Fe, Si, Pb

* See American Society of Metals *Handbook*.

consisting essentially of hard carbides are also used for phonograph needles.

Spring materials are extremely important in meters, and increasing use is found for drift-free precision springs made of age-hardening copper-beryllium alloys or special nickel alloys such as Z nickel.

Alloys suitable for precision resistance wires or compensating resistance wires were mentioned previously and also materials characterized by a low temperature coefficient of the modulus of elasticity, such as Elinvar, which is an Invar with the addition of 12 per cent chromium.

OTHER APPLICATIONS

Dry Disk Rectifiers. There are three types of dry disk rectifiers, the copper-oxide rectifier, the cupric-sulphide rectifier, and the selenium rectifier. It appears that the selenium rectifier has a large number of applications, and a special high-purity selenium has been developed for these purposes. The actual preparation of the rectifying layers is quite complicated, and a large amount of patent literature has appeared on this subject recently. Among the latest reports on this work, it has been claimed that useful rectification can be obtained from junctions between selenium and cadmium, tin, or bismuth. Another rather recent development has been the selenium versus aluminum junction. In the cupric-sulphide rectifier, pure magnesium is used against cupric sulphide, and this combination is treated in such a way as to form a rectifying layer.

It has been disclosed recently that the copper-cuprous-oxide-type junction can be made by electrolytic deposition of a layer of cuprous oxide on copper.

In a wet type of rectifier, tantalum has found widespread use because of its ability to form a rectifying layer when immersed in certain solutions. Tantalum's resistance to corrosion is useful in this application. Such rectifiers have found their places as reliable charging sources for railway signal batteries, telephone-exchange battery chargers, and "trickle" chargers for storage batteries.

Table IV. Special Alloys for Meters*

Low Temperature-Resistance Coefficient	
Manganin	84 Cu, 12 Mn, 4 Ni. Resistivity = 48×10^{-6} per cubic centimeter
High Mn	67 Mn, 28 Ni, 5 Cu. Resistivity = 220×10^{-6} per cubic centimeter
High Mn	60 Mn, 39 Ni, 1 Cu. Resistivity = 220×10^{-6} per cubic centimeter
Damping	87 Mn, 13 Cu. Quench 950 C. Age 450 C
Silver alloy	10 Mn, 10 Sn, 80 silver. Age. Negative coefficient
Silver alloy	17 Mn, 3 Sn, 80 silver. Age. Zero coefficient
Palladium-silver alloys	56 palladium-44 silver
Magnetic Shunt Materials—Very High Temperature Coefficient of Permeability	
Ni-Cu type	70 Ni, 30 Cu ± 2 per cent Fe or ± 1 per cent Mn plus Si
Ni-Fe type	30 to 40 Ni, remainder Fe ± Mn, Cr, Si
Low Temperature Coefficient Modulus of Elasticity	
Elinvar	36 Ni, 12 Cr, 52 Fe
Elinvar—modified	34 Ni, 4.5 Cr, 2 W, remainder Fe

* Also see Table I.

Mercury.—In addition to the application mentioned for electronic tubes, mercury is used for mercury switches, high-vacuum diffusion pumps, and thermometers, and as a sealing medium for vacuum-tight seals. Recently, also, an amalgamation process has been developed, particularly suitable for joining silver to copper.

Fusion Welding.—Pure tungsten is used for the electrodes in atomic hydrogen welding and also in a process of welding magnesium under a helium atmosphere. This latter process has been perfected for commercial use only within the last few months.

Capacitors. Tantalum is being used for a special type of electrolytic capacitor. A spongy tantalum material is pressed from powders which produces a condenser plate having a large surface area per unit of space occupied.

Bismuth. Bismuth may find some use in the electric-motor field because of its property of changing electrical resistance when inserted into a magnetic field. The resistance of bismuth increases when it is inserted into a transverse magnetic field. For a given field strength, the percentage change in resistance increases with a decrease in temperature. At a given temperature, the percentage change in resistance increases with an increase in field strength; for example, at a constant temperature of 18 degrees centigrade, the percentage change in resistance is 12 per cent at 4,000 gausses, 32 per cent at 8,000 gausses, 104 per cent at 20,000 gausses.

CONCLUSIONS

This review has touched upon only certain high lights of the subject under discussion. It is evident, however, that the electrical industry is vitally interested in the development of highly specialized metallurgical products. There is no question that this trend will be emphasized still more as time goes on, and we may expect new and important metallurgical developments from the research laboratories of companies closely connected with various branches comprising the electrical industry.

Ultrashort Electromagnetic Waves
V—Radiation

ANDREW ALFORD
MEMBER AIEE

In the design of radiators or antennas for ultrashort waves a complete solution by Maxwell's field equations is usually not practicable and, in many cases, not possible. It is therefore necessary to resort to engineering approximations based upon known physical phenomena. In this article the author discusses a method to be employed when the distribution of the current and the charge over the surface of the radiator are known. A subsequent issue will carry a continuation of this article in which a second method for the calculation of the field in space will be developed on the basis of the known field distribution in the immediate vicinity of the radiator as obtained from experimental data. The author is well known in the field of antenna design and is to a large extent responsible for the development of the instrument landing system used by the Civil Aeronautics Authority. This article is the fifth in a series presented originally as lectures before the basic science group of the AIEE New York Section.

PAUL C. CROMWELL, Chairman, Symposium Committee
(College of Engineering, New York University, New York, N. Y.)

TWO previous lectures[3,4] have been devoted to the subject of propagation of electromagnetic energy along transmission lines and guides. In wave guides and transmission lines the lines of force are allowed to propagate along one dimension only; the propagation along the remaining two dimensions is restricted. Thus, for example, the lines of electric and magnetic forces are confined to the space between the outer and the inner conductors of a concentric transmission line and are allowed to travel only in the direction of the axis of these conductors. Similarly, in a hollow wave guide the waves propagate mainly along the axis of the guide.

In this paper we shall consider the phenomena which take place when electromagnetic energy is allowed to spread out into unlimited space. In practice these phenomena occur when a transmission line or a hollow wave guide is left open-ended, and the waves which propagate along them are thus permitted to continue their travel into unbounded space.

The nature of the open end determines what proportion of the power is reflected back into the guide and what is radiated into space. The open end acts as a transformer between the two modes of propagation. The impedance of a guide is usually very different from the impedance of open space. For this reason, when a guide is terminated abruptly, the impedance match at the open end is very poor; most of the power which arrives

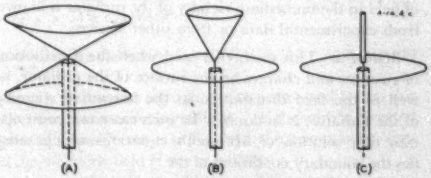


Figure 1. Examples of radiators

at the end is reflected back into the guide, and only a small portion of the power is radiated into space. When it is desired that a greater portion of the power be radiated into space, the end of the transmission line or guide is so arranged that a better match of impedance of free space and of the guide is obtained. Such modified ends are usually referred to as electromagnetic horns and antennas, or radiators.

It is difficult to draw a line between what is called an antenna and what is called an electromagnetic horn, because there is no real distinction between them. This difficulty becomes quite evident from Figure 1 in which there are shown several radiating terminations of a concentric transmission line. Termination *A* would almost certainly be called an electromagnetic horn. Termination *C* is a familiar antenna. Termination *B* may be called anything you like.

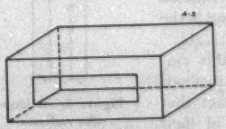


Figure 2. A metal box with an aperture

There are still other types of radiators. For example, an opening in a metal box which contains high-frequency circuits, as in Figure 2, or a looplike end of a short-

Andrew Alford is head of the air navigation laboratory, Federal Telephone and Radio Corporation, New York, N. Y.

circuited two-wire transmission line, as in Figure 3, are also radiators. These examples, of course, do not exhaust the list of various forms of radiators, but they are sufficient to give us some idea of the variety of shapes which radiators can have.

For the purposes of design and other reasons, it is often necessary to be able to calculate the radiation field of the various types of radiators with some accuracy. At the present time there are three different approaches which are in use. Which one of these three methods is used in a particular case depends primarily on the nature of the problem.

Method 1. This method is used when the distribution of currents and charges over the surface of the radiator is known, either from other calculations or from experiments.

Method 2. This method is used when the distribution of field in the immediate vicinity of the radiator is known from experimental data or from other sources.

Method 3. This method is used when the distribution of currents and charges on the surface of the radiator, as well as the field distribution in the immediate vicinity of the radiator, is in doubt. In such cases one must obtain that solution of Maxwell's equations which satisfies the boundary conditions of the problem. From such a solution not only the field at a distance, but also the current distribution along the radiator, can be calculated. This method is applicable to all radiation problems. Of the three methods it is the most difficult one to use, particularly when the shape of the radiator is not very simple. It will not be possible, within the confines of this paper, to describe in detail all three methods. We shall therefore confine ourselves to the first two, the first method being covered in this article and the second in the subsequent one.

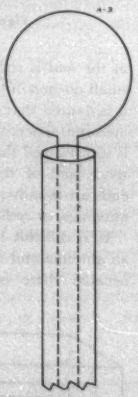


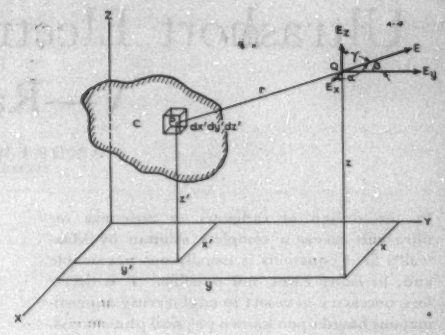
Figure 3. A loop-like radiator

The justification of this emphasis on the first two methods is to be found in the fact that these methods, because of their relative simplicity, are used more frequently in engineering calculations.

METHOD 1

This method normally is applied to so-called antennas. The application of this method becomes particularly simple when the radiator consists of one or more wires in which the current distribution is sinusoidal.

In order to obtain the equations which are used in method 1, let us calculate the electromagnetic field



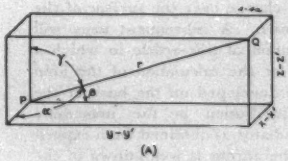


Figure 4

Auxiliary figure to explain scalar potential

$$E_x = E\cos\alpha$$
$$E_y = E\cos\beta$$
$$E_z = E\cos\gamma$$
$$\cos\alpha = \frac{x-x'}{r}$$
$$\cos\beta = \frac{y-y'}{r}$$
$$\cos\gamma = \frac{z-z'}{r}$$
$$E_x = E\cdot\frac{x-x'}{r}$$
$$E_y = E\cdot\frac{y-y'}{r}$$
$$E_z = E\cdot\frac{z-z'}{r}$$

produced by the currents and charges which are carried by a good conductor C in Figure 4. It will be assumed that the current density at every point on the surface and inside the conductor is known. This quantity is a vector which may have different directions at different points. Let i_x, i_y, and i_z be the components of this vector at a point $P(x', y', z')$ in the conductor. Each of these three components is a function of co-ordinates x', y', z'. Let ρ be the charge density at point $P(x', y', z')$. This is a scalar quantity which is also a function of coordinates x', y', z'.

In accordance with the law of Coulomb a fixed charge q concentrated at a point $P(x', y', z')$ in free space produces a field $E = q/r^2$ at a point $Q(x, y, z)$ located at a distance $r = \sqrt{(x-x')^2+(y-y')^2+(z-z')^2}$ from P. This field E is a vector which points along line PQ and in the direction from P to Q. The three components of this vector are (see Figure 4a)

$$\left.\begin{aligned} E_x &= \frac{q}{r^2}\frac{x-x'}{r} \\ E_y &= \frac{q}{r^2}\frac{y-y'}{r} \\ E_z &= \frac{q}{r^2}\frac{z-z'}{r} \end{aligned}\right\} \quad (1)$$

All of these three components can be obtained by partial differentiation of a scalar quantity $V = q/r$ which is

called the scalar potential. Since

$$r^2=(x-x')^2+(y-y')^2+(z-z')^2$$

then

$$\left.\begin{aligned} r\frac{\partial r}{\partial x}&=x-x'\\ r\frac{\partial r}{\partial y}&=y-y'\\ r\frac{\partial r}{\partial z}&=z-z' \end{aligned}\right\} \tag{2}$$

and

$$\left.\begin{aligned} E_x&=-\frac{\partial V}{\partial x}=-\frac{\partial}{\partial x}\left(\frac{q}{r}\right)=\frac{q}{r^2}\frac{\partial r}{\partial x}=\frac{q}{r^3}\frac{x-x'}{r}\\ E_y&=-\frac{\partial V}{\partial y}=\frac{q}{r^3}\frac{y-y'}{r}\\ E_z&=-\frac{\partial V}{\partial z}=\frac{q}{r^3}\frac{z-z'}{r} \end{aligned}\right\} \tag{3}$$

When the charge density ρ is known at every point in body C, and the charges are static, that is, when they

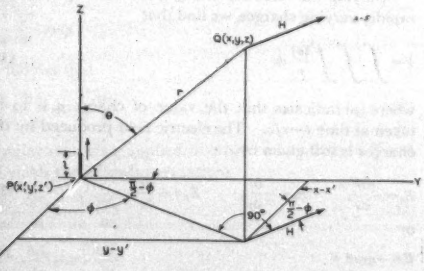


Figure 5. Biot-Savart law for a current element

$$H=\frac{Il}{cr^2}\sin\theta$$

do not vary rapidly with time, the three components of the electric field $\boldsymbol{E}$ can be calculated easily. Since the charge inside volume element $dx'dy'dz'$ around $P(x', y', z')$ is $\rho dx'dy'dz'$ the x component of $\boldsymbol{E}$ due to this charge is

$$dE_x=\frac{\rho dx'dy'dz'}{r^2}\frac{x-x'}{r}=-\frac{\partial}{\partial x}\left(\frac{\rho}{r}\right)\cdot dx'dy'dz' \tag{4}$$

The total E_x is therefore

$$E_x=-\int\int_C\int\frac{\partial}{\partial x}\left(\frac{\rho}{r}\right)dx'dy'dz'=-\frac{\partial}{\partial x}\int\int_C\int\frac{\rho}{r}\,dx'dy'dz'$$

$$=-\frac{\partial V}{\partial x} \tag{5}$$

where

$$V=\int\int_C\int\frac{\rho}{r}\,dx'dy'dz' \tag{6}$$

The $\partial/\partial x$ was carried outside the integral sign, because x is a parameter, the integration being performed with respect to x', y', z' and not with respect to x, y, z. This fact allows us to perform partial differentiation with respect to x before or after the integration. The other two components of $\boldsymbol{E}$ are found to be

$$E_y=-\frac{\partial V}{\partial y},\quad E_z=-\frac{\partial V}{\partial z} \tag{7}$$

where V has the same value as in equations 6 and 5.

The components of the *magnetic* field due to a steady or slowly varying distribution of currents can also be calculated readily by a procedure very similar to that which was just used to calculate the electric field due to a known distribution of charges.

This time we start with Biot-Savart's law (see Figure 5). According to this law a current I flowing through a very short wire of length l located at $P(x'y'z')$ produces at $Q(x, y, z)$ a magnetic field

$$H=\frac{Il}{cr^2}\sin\theta \text{ (in Gaussian units)} \tag{8}$$

which is directed at right angles to both r and l. In this equation c is the velocity of light. If the wire is directed parallel to the Z axis, as in Figure 5, the three components of the magnetic field H are as follows:

$$\left.\begin{aligned} H_x&=-\frac{Il}{cr^3}\frac{y-y'}{r}\\ H_y&=\frac{Il}{cr^3}\frac{x-x'}{r}\\ H_z&=0 \end{aligned}\right\} \tag{9}$$

Again, as in the case of the three components of the electric field, all three components may be calculated easily from an auxiliary function $\boldsymbol{A}=Il/c\boldsymbol{r}$. This time, however, this auxiliary quantity itself is a vector and is therefore called vector potential. The direction of vector $\boldsymbol{A}$ is by definition the same as that of current I (see Figure 6).

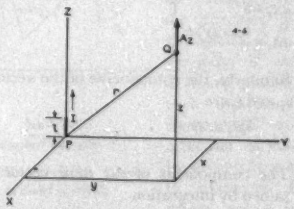


Figure 6. Vector potential of a current element (I, l)

$$A_z=\frac{Il}{cr}$$
$$A_x=0$$
$$A_y=0$$

If the direction of current I is parallel to the Z axis, then the components of $\boldsymbol{A}$ are

$$\left.\begin{aligned} A_x&=0\\ A_y&=0\\ A_z&=\frac{Il}{cr} \end{aligned}\right\} \tag{10}$$

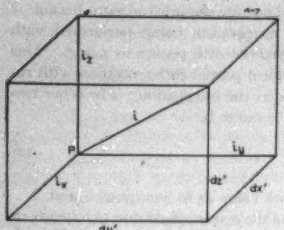


Figure 7. Current intensity i at a point P may be resolved into three components, i_x, i_y, i_z

The components of the magnetic field H may be obtained from the components of vector potential A by the following rules

$$\left.\begin{aligned} H_x &= \frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} = -\frac{Il}{cr^2}\,\frac{y-y'}{r} \\ H_y &= \frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} = +\frac{Il}{cr^2}\,\frac{x-x'}{r} \\ H_z &= \frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} = 0 \end{aligned}\right\} \qquad (11)$$

In vector shorthand these relationships are usually written in one of the following ways

$$H = \text{curl } A, \quad H = \nabla \times A, \quad H = \text{rot } A \qquad (12)$$

depending on which particular brand of notation is preferred by the writer.

In order to calculate the magnetic field of currents flowing in the solid conductor C in Figure 4, the following procedure may be used. Let i_x, i_y, i_z be the components of current density i at point $P(x', y', z')$ inside the conductor (Figure 7).

Then, the components of the vector potential due to i_z are

$$\left.\begin{aligned} dA_x &= 0 \\ dA_y &= 0 \\ dA_z &= \frac{(i_z dx' dy')dz'}{cr} \end{aligned}\right\} \qquad (13)$$

Similarly, the components of the vector potential due to i_y and i_x are

$$dA_y = \frac{i_y dz' dx' dy'}{cr}, \qquad dA_z = \frac{i_z dy' dz' \cdot dx'}{cr} \qquad (14)$$

The components of the total vector potential are obtained by integration

$$A_x = \int_C\int\int \frac{i_x dy' dz' dx'}{cr}, \qquad A_y = \int_C\int\int \frac{i_y dz' dx' dy'}{cr},$$

$$A_z' = \int_C\int\int \frac{i_z' dx' dy' dz'}{cr} \qquad (15)$$

From these, the components of the magnetic field are obtained by means of equations 12 or 11. In vector notation these results may be written as follows:

$$A = \frac{1}{c}\int_C\int\int \frac{i}{r}\,dv \qquad (16)$$

$$H = \text{curl } A \qquad (17)$$

So far we have considered the case of steady currents or currents varying so slowly that both magnetic and electric fields may be assumed to propagate instantaneously. When the currents vary with time so rapidly that a considerable change in current takes place while the magnetic field due to this current propagates a distance r, we may still calculate the vector potential from equations 16, but this time, however, if we wish to get A at time t, we must use, under the integral, current density i at time $t-r/c$ to allow for time of travel. The quantity r/c is the time taken by the field to traverse distance r when traveling with the velocity of light c. To remind ourselves that we must use the value of current density at time $t-r/c$, we shall write $[i]$ instead of i. Therefore

$$A = \frac{1}{c}\int\int\int \frac{[i]}{r}\,dv \qquad (18)$$

$$H = \text{curl } A \qquad (17)$$

Applying the same reasoning to the scalar potential of rapidly varying charges, we find that

$$V = \int\int\int \frac{[\rho]}{r}\,dv \qquad (19)$$

where $[\rho]$ indicates that the value of charge ρ is to be taken at time $t-r/c$. The electric field produced by the charges is still given by

$$E_x = -\frac{\partial V}{\partial x}, \qquad E_y = -\frac{\partial V}{\partial y}, \qquad E_z = -\frac{\partial V}{\partial z} \qquad (20)$$

or

$$E = -\text{grad } V$$

This field, however, is only a part of the total field. There is another part E' which appears whenever

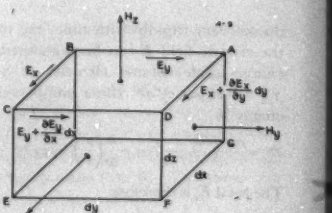


Figure 8. Used in deriving equations 21, 22, 23

$$dE_y = \frac{\partial E_y}{\partial x}\,dx$$

$\partial H/\partial t \neq 0$. In order to evaluate E' let us consider a volume element whose sides are $dxdydz$ (see Figure 8). Let us assume that, at a point inside the element, there is a magnetic field H whose components are H_x, H_y, H_z. Then $H_z dxdy$ may be regarded as flux which links perimeter $ABCD$. If flux $H_z dxdy$ is varying with time

there is produced an electromotive force

$$\frac{1}{c}\frac{\partial(H_z dxdy)}{\partial t}$$

around the perimeter $ABCD$. This electromotive force must be equal to the sum of potential drops around $ABCD$. The potential difference between

B and C is $+E_x dx$

C and D is $+\left(E_y+\frac{\partial E_y}{\partial x}dx\right)dy$

D and A is $-\left(E_x+\frac{\partial E_x}{\partial y}dy\right)dx$

A and B is $-E_y dy$

The sum of all potential drops around the circuit is therefore

$$E_x dx'-\left(E_x+\frac{\partial E_x}{\partial y}dy\right)dx+\left(E_y+\frac{\partial E_y}{\partial x}dx\right)dy-E_y dy=\left(\frac{\partial E_y}{\partial x}-\frac{\partial E_x}{\partial y}\right)dxdy$$

and this must be equal to the electromotive force

$$-\frac{1}{c}\frac{\partial H_z}{\partial t}dxdy$$

It follows that

$$\frac{\partial E_y}{\partial x}-\frac{\partial E_x}{\partial y}=-\frac{1}{c}\frac{\partial H_z}{\partial t} \tag{21}$$

Similar reasoning applied to other components of $\boldsymbol{E}$ and $\boldsymbol{H}$ yields the following equations

$$\frac{\partial E_z}{\partial y}-\frac{\partial E_y}{\partial z}=-\frac{1}{c}\frac{\partial H_x}{\partial t} \tag{22}$$

$$\frac{\partial E_x}{\partial z}-\frac{\partial E_z}{\partial x}=-\frac{1}{c}\frac{\partial H_y}{\partial t} \tag{23}$$

These three equations, 21, 22, 23, may be written in vector notation as one equation

$$\text{curl } \boldsymbol{E}=-\frac{1}{c}\frac{\partial \boldsymbol{H}}{\partial t} \tag{24}$$

We have already seen that

$$\boldsymbol{H}=\text{curl } \boldsymbol{A} \tag{17}$$

By substituting this value of $\boldsymbol{H}$ into equation 24, we find that

$$\text{curl } \boldsymbol{E}=-\frac{1}{c}\frac{\partial}{\partial t}(\text{curl } \boldsymbol{A})$$

Hence

$$\text{curl } \boldsymbol{E}=\text{curl}\left(-\frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial t}\right) \tag{25}$$

It is quite clear that

$$\boldsymbol{E}=-\frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial t} \tag{26}$$

would satisfy equation 25. To this solution, however, we are quite free to add a gradient of any function because the curl of the gradient of any scalar is zero. It so happens that we can easily surmise what we should add, because the part to be added must reduce to $-\text{grad } V$ when there are no varying currents. In such cases both $\partial \boldsymbol{H}/\partial t=0$ and $\partial \boldsymbol{A}/\partial t=0$. The total electric field is thus

$$\boldsymbol{E}=-\frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial t}-\text{grad } V \tag{27}$$

It is well to stop for a moment and inquire a bit farther into the nature of term $\boldsymbol{E}'=-(1/c)(\partial \boldsymbol{A}/\partial t)$. Let us consider two closed circuits S_1 and S_2 in Figure 9. Let us assume that current I is flowing in circuit S_1. The vector potential of current I is

$$\boldsymbol{A}=\frac{1}{c}\oint_{S_1}\frac{[\boldsymbol{I}]}{r}dS_1 \tag{28}$$

If the frequency we are dealing with is sufficiently low, the dimensions of circuits S_1, S_2, and of the distances between them are all small in comparison with the wave length. It will therefore make no substantial difference whether we use I at time t or at time $t-r/c$. Besides, current I will be substantially constant around S_1. Accordingly

$$\boldsymbol{A}=\frac{1}{c}\oint_{S_1}\frac{\boldsymbol{I}}{r}dS_1 \tag{29}$$

and

$$\boldsymbol{E}'=-\frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial t}=-\frac{\partial}{\partial t}\left\{\frac{1}{c^2}\oint_{S_1}\frac{\boldsymbol{I}}{r}dS_1\right\} \tag{30}$$

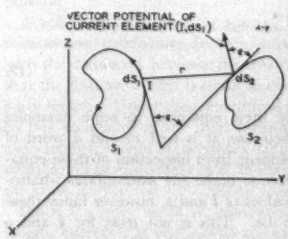


Figure 9. Coupled circuits

Current I flowing in closed circuit S_1 induces electromotive force in closed circuit S_2

This $\boldsymbol{E}'$ is, of course, a vector. If we wish to calculate the component of $\boldsymbol{E}'$ in any direction, for example, in the direction of element dS_2 of S_2, we may, if we so desire, project each individual element $d\boldsymbol{E}'$ on direction of dS_2 by writing $I\cos\epsilon$ in place of $\boldsymbol{I}$ where $\cos\epsilon$ is the angle between $\boldsymbol{I}$ and dS_2 (see Figure 9). The component of $\boldsymbol{E}'$ in the direction of dS_2 is thus

$$E'_{dS_2}=-\frac{\partial}{\partial t}\left\{\frac{1}{c^2}\oint_{S_1}\frac{I\cos\epsilon}{r}dS_1\right\}=-\frac{\partial}{\partial t}\left[\frac{1}{c^2}\oint_{S_1}\frac{\cos\epsilon}{r}dS_1\right]$$

where I is the scalar magnitude of $\boldsymbol{I}$. Since $E'_{dS_1}dS_2$ is the electromotive force induced in element dS_2, it is clear that $\left[\frac{1}{c^2}\oint\frac{\cos\epsilon}{r}dS_1\right]dS_2$ is the mutual inductance be-

tween circuit S_1 and element dS_2. By integrating with respect to dS_2 around circuit S_2, we find the total electromotive force induced in this circuit:

$$\text{emf} = -\frac{\partial I}{\partial t}\left\{\frac{1}{c^2}\oint_{S_2}\oint_{S_1}\frac{\cos\epsilon}{r}\,dS_1 dS_2\right\} = -\frac{\partial I}{\partial t}M \tag{31}$$

where

$$M = \frac{1}{c^2}\oint_{S_2}\oint_{S_1}\frac{\cos\epsilon}{r}\,dS_1 dS_2 \tag{32}$$

The quantity M is the mutual inductance between circuits S_1 and S_2.

It is thus clear that term $-(1/c)(\partial A/\partial t)$ in equation 27 replaces the familiar $-(\partial I/\partial t)\ M$ of low-frequency equations. This term $-(1/c)(\partial A/\partial t)$ reduces to $-(\partial I/\partial t)M$ when frequency is so low that the magnitude of current around the circuit is substantially constant, and the time of propagation is small in comparison with the period.

The inquiry into the nature of $-(1/c)(\partial A/\partial t)$ has taken us a bit off our path, and it is well now to take stock of the results. We have shown that, when the currents and charges are varying rapidly with time, the magnetic field

$$H = \text{curl } A \tag{17}$$

where

$$A = \frac{1}{c}\int\int\int\frac{[i]}{r}\,dv \tag{18}$$

and that the electric field

$$E = -\frac{1}{c}\frac{\partial A}{\partial t} - \text{grad } V \tag{27}$$

where

$$V = \int\int\int\frac{[\rho]}{r}\,dv \tag{19}$$

Before we apply these equations to some examples which illustrate their use, it is well to add a word of caution. It may appear from inspection of these equations that we are free to make any assumptions whatsoever in regard to values of i and ρ, however fancy these assumptions might be. This is not true, for i and ρ must obey the continuity equation. This equation is

$$\frac{\partial i_x}{\partial x'} + \frac{\partial i_y}{\partial y'} + \frac{\partial i_z}{\partial z'} = -\frac{\partial \rho}{\partial t} \tag{33}$$

or in vector notation

$$\text{div } i = -\frac{\partial \rho}{\partial t} \tag{34}$$

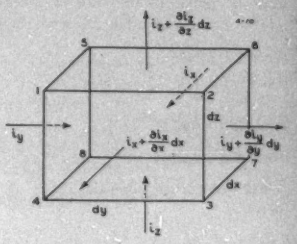
The meaning of this equation becomes clear if both sides of it are multiplied by $dx'dy'dz'$, and the physical significance of the terms is visualized with the aid of Figure 10.

$$\left(\frac{\partial i_x}{\partial x'}dx'\right)dy'dz' + \left(\frac{\partial i_y}{\partial y'}dy'\right)dx'dz' + \left(\frac{\partial i_z}{\partial z'}dz'\right)dx'dy' = -\frac{\partial \rho}{\partial t}dx'dy'dz' \tag{35}$$

The first term $\left(\frac{\partial i_x}{\partial x'}dx'\right)dy'dz' = \left(i_x dz'dy' + \frac{\partial i_x}{\partial x}dz'dy'\right) - i_x dz'dy'$

is equal to the difference between the current which flows out of volume $dx'dy'dz'$ through face 1, 2, 3, 4, and the

Figure 10. Used in deriving equation 22



current which flows into $dx'dy'dz'$ through face 5, 6, 7, 8. Similarly, the other two terms on the left-hand side represent the differences between the currents flowing *out of* and flowing *into* the other pairs of faces of volume $dx'dy'dz'$. The entire left-hand side of equation 35 represents the difference between the current leaving the volume and the current entering this volume. The difference between these two currents can be made up only by depleting the total charge $\rho dx'dy'dz'$ within the volume. Equation 33 states this fact in mathematical terms.

If our assumptions in regard to i and ρ contradict equation 33, we have an impossible combination of i and ρ, and we should not be surprised to end up with E and H which are incompatible with each other.

The same equation can be approached from another point of view. At any point in space E and H must satisfy Maxwell's equations: [1,5,6,7,8]

$$\text{curl } E = -\frac{1}{c}\frac{\partial H}{\partial t} \quad (a) \qquad \text{div } H = 0 \quad (b)$$

$$\text{curl } H = +\frac{1}{c}\frac{\partial E}{\partial t} \quad (d) \qquad \text{div } E = 0 \quad (c)$$

We have seen already that E is such that equation a is satisfied. In fact, this equation was used in evaluating E. Equation b is satisfied by H because $H = \text{curl } A$ and the divergence of the curl of any vector is zero. If our values of E and H are substituted into equation c it reduces to

$$\frac{\partial}{\partial t}\left(-\frac{1}{c}\text{div } A\right) - \nabla^2 V = 0 \tag{36}$$

where

$$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$$

Since $[\rho] = f(x', y', z', (t - r/c)]$, the quantity $u = [\rho]/r$

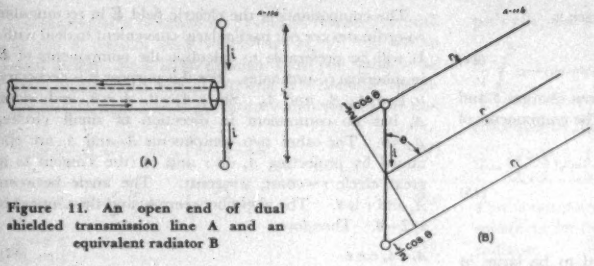


Figure 11. An open end of dual shielded transmission line A and an equivalent radiator B

satisfies the following equation $\nabla^2 U-(1/c^2)(\partial^2 u/\partial t^2)=0$. The integral $V=\int\int\int([\rho]/r)dv$, which is a sum of the u's, satisfies a similar equation

$$\nabla^2 V-\frac{1}{c^2}\frac{\partial^2 V}{\partial t^2}=0 \tag{37}$$

By substituting the value of $\nabla^2 V$ from equation 37 into 36, we find that

$$\frac{\partial}{\partial t}\left(-\frac{1}{c}\operatorname{div} \boldsymbol{A}\right)-\frac{1}{c^2}\frac{\partial^2 V}{\partial t^2}=0 \tag{38}$$

By integrating equation 38 with respect to t, we get

$$-\frac{1}{c}\operatorname{div} \boldsymbol{A}-\frac{1}{c^2}\frac{\partial V}{\partial t}=\varphi(x, y, z) \tag{39}$$

Next, we substitute $\boldsymbol{H}=\operatorname{curl} \boldsymbol{A}$, $\boldsymbol{E}=-(1/c)(\partial \boldsymbol{A}/\partial t)-\operatorname{grad} V$ into equation d. Since $\boldsymbol{i}=\boldsymbol{F}[x', y', z', t-(r/c)]$, the quantity $v=([\boldsymbol{i}]/r)$ satisfies an equation similar to equation 37 and so does the integral $\boldsymbol{A}=(1/c)\times\int\int\int([\boldsymbol{i}]/r)dv$, that is,

$$\nabla^2 \boldsymbol{A}-\frac{1}{c^2}\frac{\partial \boldsymbol{A}^2}{\partial t^2}=0 \tag{40}$$

Since

$$\operatorname{curl}(\operatorname{curl} \boldsymbol{A})=-\nabla^2 \boldsymbol{A}+\operatorname{grad}(\operatorname{div} \boldsymbol{A})$$

we find that equation d reduces to

$$-\nabla^2 \boldsymbol{A}+\operatorname{grad}(\operatorname{div} \boldsymbol{A})=-\frac{1}{c^2}\frac{\partial^2 \boldsymbol{A}}{\partial t^2}-\operatorname{grad}\left(\frac{1}{c}\frac{\partial V}{\partial t}\right)$$

which in view of equation 40 becomes

$$\operatorname{grad}\left(\operatorname{div} \boldsymbol{A}+\frac{1}{c}\frac{\partial V}{\partial t}\right)=0 \tag{41}$$

By comparing equation 41 with equation 39 we see that $\operatorname{grad}\varphi(x, y, z)=0$, that is, $\partial\varphi/\partial x=0$, $\partial\varphi/\partial y=0$, $\partial\varphi/\partial z=0$. This is possible only when $\varphi=$ a constant $=k$. At very large distances from the radiator $\boldsymbol{A}=0$, $V=0$, also $\operatorname{div}\boldsymbol{A}=0$ and $\partial v/\partial t=0$. Therefore, the left-hand side of equation 39 which we have just proved to be equal to k is zero. It follows that

$$\operatorname{div} \boldsymbol{A}+\frac{1}{c}\frac{\partial V}{\partial t}=0 \tag{42}$$

* It can be shown that equation 42 holds good even within the conductor.

at all points in space.* When values of $\boldsymbol{A}$ and V are substituted, equation 42 reduces to a relation between $\boldsymbol{i}$ and ρ. After some manipulation (which will not be reproduced here) equation 42 reduces to[8]

$$\operatorname{div} \boldsymbol{i}+\frac{\partial \rho}{\partial t}=0 \tag{34}$$

plus the requirement that the current is not allowed either to enter or leave the volume over which the integral $(1/c)\int\int\int([\boldsymbol{i}]/r)dv$ is taken. This condition is obviously satisfied when the integral is extended over all regions where $\boldsymbol{i}\neq 0$, which is exactly what we agreed to do. This limitation is therefore of interest only when one is calculating the field of a part of a conductor. In such cases the limitation may be side-stepped by providing assumed charges into which or out of which the current is allowed to flow, and by adding the potential of these charges to $\int\int\int([\rho]/r)dv$ or by extending this integral itself over these charges.

We shall now illustrate the use of equations 17, 18, 27, and 19 by applying them to a simple example.

In Figure 11 is shown an "open end" of a dual shielded transmission line. The two conductors of the transmission line are bent at right angles and are provided with small spherical end condensers. This somewhat unusual arrangement was chosen in order that the integrations which we shall have to perform may be as simple as possible.

It will be assumed that the spacing between the transmission-line conductors is very small in comparison with the distance l between the two end capacitors and that the distance l itself is small in comparison with the wave length. Under these conditions the field produced by one conductor of the dual transmission line will be canceled by the field of the other conductor, and arrangement A will be equivalent to B, in that both will produce the same field in the surrounding space.

Since l is very small in comparison with the wave length, current I is very nearly constant along the wire joining the two capacitors. If the charges on the end capacitors at time t are q and $-q$, currents I and q are such that

$$I=-\frac{\partial q}{\partial t} \tag{43}$$

This equation takes the place of

$$\operatorname{div} \boldsymbol{i}=\frac{\partial i_z}{\partial z}=-\frac{\partial \rho}{\partial t}$$

because we are assuming that the current at the end capacitors is changing abruptly from I to 0 so that

$$\frac{\partial i_z}{\partial z}dv=I=-\frac{\partial \rho}{\partial t}dv=-\frac{\partial q}{\partial t}$$

The scalar potential at a point Q in space is

$$V=\int\int\int\frac{[\rho]}{r}dv=\frac{[q]}{r_1}+\frac{[-q]}{r_2} \tag{44}$$

where r_1 and r_2 are the distances between charges q and $-q$ and the point of observation Q. The components of the vector potential are

$$A_z=\frac{1}{c}\int\int\int\frac{[i]}{r}dv=\frac{1}{c}\int_0^l\frac{[I]}{r}dz=\frac{1}{c}\frac{[I]l}{r} \tag{45}$$

$$A_x=0 \qquad A_y=0$$

provided, of course, that r is assumed to be large in comparison with l. When $I=I_0\sin\omega t$, the charge q is

$$q=-\int Idt=\frac{I_0}{\omega}\cos\omega t$$

Accordingly, from equations 45 and 44

$$A_z=\frac{1}{c}\frac{I_0\sin\omega\left(t-\frac{r}{c}\right)}{r}l \tag{46}$$

$$V=\frac{\frac{I_0}{\omega}\cos\omega\left(t-\frac{r_1}{c}\right)}{r_1}-\frac{\frac{I_0}{\omega}\cos\omega\left(t-\frac{r_2}{c}\right)}{r_2} \tag{47}$$

When l is very small in comparison with r and with λ

$$r_1=r+\frac{l}{2}\cos\theta, \qquad r_2=r-\frac{l}{2}\cos\theta, \qquad \cos\left(\frac{\omega l}{2c}\cos\theta\right)=1,$$

$$\sin\left(\frac{\omega l}{2c}\cos\theta\right)=\frac{\omega l}{2c}\cos\theta \text{ (see Figure 11)}$$

and equation 47 becomes

$$V=-\frac{I_0}{\omega}\left\{\frac{\cos\omega\left(t-\frac{r}{c}\right)}{r^2}l\cos\theta-\frac{\sin\omega\left(t-\frac{r}{c}\right)\frac{\omega l}{c}\cos\theta}{r}\right\} \tag{48}$$

The components of the magnetic field are $H_x=\frac{\partial A_y}{\partial x}-\frac{\partial A_x}{\partial y}=0$

$$H_y=\frac{\partial A_x}{\partial z}-\frac{\partial A_z}{\partial x}=-\frac{\partial A_z}{\partial x}=-\frac{\partial}{\partial x}\left\{\frac{I_0\sin\omega\left(t-\frac{r}{c}\right)}{cr}l\right\}$$

$$H_z=\frac{\partial A_z}{\partial y}-\frac{\partial A_y}{\partial z}=+\frac{\partial A_z}{\partial y}=\frac{\partial}{\partial y}\left\{\frac{I_0\sin\omega\left(t-\frac{r}{c}\right)}{cr}l\right\}$$

Hence

$$H_y=\left[\frac{I_0l}{cr^2}\sin\omega\left(t-\frac{r}{c}\right)+\frac{\omega}{c^2}\frac{I_0l}{r}\cos\omega\left(t-\frac{r}{c}\right)\right]\frac{x}{r} \tag{49}$$

$$H_z=\left[-\frac{I_0l}{cr^2}\sin\omega\left(t-\frac{r}{c}\right)-\frac{\omega}{c^2}\frac{I_0l}{r}\cos\omega\left(t-\frac{r}{c}\right)\right]\frac{y}{r} \tag{50}$$

The total H is

$$H=\sqrt{H_z^2+H_y^2}=\left[\frac{I_0l}{cr^2}\sin\omega\left(t-\frac{r}{c}\right)+\frac{\omega}{c^2}\frac{I_0l}{r}\cos\omega\left(t-\frac{r}{c}\right)\right]\times\frac{\sqrt{x^2+y^2}}{r} \tag{51}$$

The components of the electric field $\boldsymbol{E}$ in rectangular co-ordinates are not particularly convenient to deal with. It will be preferable to calculate the components of $\boldsymbol{E}$ in spherical co-ordinates. For this purpose it is necessary to find A_φ, A_r, and A_θ. Since $A_x=0$, $A_y=0$, and, since A_z has no component in direction of small circles, $A_\varphi=0$. The other two components A_θ and A_r are obtained by projecting A_z on r and on the tangent to a great circle $r=\text{const}$, $\varphi=\text{const}$. The angle between A_z and r is θ. The angle between A_z and the tangent is $\pi/2-\theta$. Therefore

$$A_r=A_z\cos\theta \tag{52}$$

and

$$A_\theta=-A_z\cos\left(\frac{\pi}{2}-\theta\right)=-A_z\sin\theta \tag{53}$$

The line element in spherical co-ordinates is given by

$$ds^2=dr^2+r^2d\theta^2+(r\sin\theta)^2d\varphi^2$$

The three components of gradient are therefore

$$\left.\begin{aligned}\text{grad}_r\,V&=\frac{\partial V}{\partial r}\\ \text{grad}_\theta\,V&=\frac{\partial V}{r\partial\theta}\\ \text{grad}_\varphi\,V&=\frac{1}{r\sin\theta}\frac{\partial V}{\partial\varphi}\end{aligned}\right\} \tag{54}$$

The last component is equal to zero, because V does not depend on φ. From equation 27

$$E_r=-\frac{1}{c}\frac{\partial Ar}{\partial t}-\text{grad}_r\,V$$

This equation, in view of equations 48, 54, and 52, becomes

$$E_r=-\frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\frac{1}{c}I_0\sin\omega\left(t-\frac{r}{c}\right)}{r}l\cos\theta\right]+\frac{\partial}{\partial r}\omega\left[\frac{\cos\omega\left(t-\frac{r}{c}\right)}{r^2}l\cos\theta-\frac{\sin\omega\left(t-\frac{r}{c}\right)}{r}\frac{\omega l}{c}\cos\theta\right]$$

$$=-\frac{2I_0l}{\omega}\frac{\cos\theta}{r^3}\left[\frac{1}{r}\cos\omega\left(t-\frac{r}{c}\right)-\frac{\omega}{c}\sin\omega\left(t-\frac{r}{c}\right)\right] \tag{55}$$

Similarly we find that

$$E_\theta=-\frac{1}{c}\frac{\partial A_\theta}{\partial t}-\text{grad}_\theta\,V$$

$$=-\frac{1}{c}\frac{\partial}{\partial t}\left[-\frac{1}{c}\frac{I_0\sin\omega\left(t-\frac{r}{c}\right)}{r}l\sin\theta\right]-\frac{1}{r}\frac{\partial}{\partial\theta}\left\{-\frac{I_0}{\omega}\left[\frac{\cos\omega\left(t-\frac{r}{c}\right)}{r^2}l\cos\theta-\frac{\sin\omega\left(t-\frac{r}{c}\right)}{r}\frac{\omega l}{c}\cos\theta\right]\right\}$$

$$E_\theta=-\frac{I_0l}{\omega}\frac{\sin\theta}{r}\left[\left(\frac{1}{r^2}-\frac{\omega^2}{c^2}\right)\cos\omega\left(t-\frac{r}{c}\right)-\frac{\omega}{cr}\sin\omega\left(t-\frac{r}{c}\right)\right] \tag{56}$$

An examination of equations 51 and 56 reveals that both H and E_θ contain terms which vary as $1/r$. E_r has no such terms. At a large distance from the radiator all other terms which vary as $1/r^2$ and $1/r^3$ become negligible in comparison with the terms which vary as $1/r$ and

$$\text{Total } H = H_\varphi = \frac{\omega}{c^2}\frac{Il}{r}\cos\omega\left(t-\frac{r}{c}\right)\sin\theta \tag{57}$$

$$\text{Total } E = E_\theta = \frac{\omega}{c^2}\frac{Il}{r}\cos\omega\left(t-\frac{r}{c}\right)\sin\theta \tag{58}$$

$$\left.\begin{aligned} E_r &= 0 \\ E_\varphi &= 0 \end{aligned}\right\} \tag{59}$$

The $1/r$ terms in both H and E_θ contain ω in the numerator. These terms may be dropped when ω is very small. The terms which remain in this case are

$$H = \frac{Il}{cr^2}\sin\theta\cdot\sin\omega t = \frac{Il}{cr^2}\sin\theta$$

$$E_\theta = -\frac{Il}{\omega}\frac{\sin\theta}{r^3}\cos\omega t = -\frac{ql}{r^2}\sin\theta$$

This value of H follows at once from the Biot-Savart law for steady or slowly varying currents. The value of E_θ is the familiar component of the field of two charges q and $-q$ separated by a very small distance l.

The fact that at a large distance from the radiator both $\boldsymbol{H}$ and $\boldsymbol{E}$ vary as $1/r$ has some very important consequences. It is well known that the Poynting vector[1] $\boldsymbol{P} = (c/4\pi)\boldsymbol{E}\times\boldsymbol{H}$ represents the power transported by the field through a unit area placed at right angles to vector $\boldsymbol{P}$. Vector $\boldsymbol{P}$ is at right angles to both $\boldsymbol{H}$ and $\boldsymbol{E}$, and its magnitude is $(c/4\pi)EH\sin\delta$, where δ is the angle between vectors $\boldsymbol{H}$ and $\boldsymbol{E}$. When $\boldsymbol{H}$ and $\boldsymbol{E}$ are at right angles with respect to each other, $\sin\delta = 1$. By substituting the values of H and E from equations 57 and 58 into the expression for P, it is found that

$$P = \frac{c}{4\pi}\left(\frac{\omega}{c^2}\right)^2\left(\frac{Il}{r}\right)^2\sin^2\theta\cos^2\omega\left(t-\frac{r}{c}\right) \tag{60}$$

If the radiator is surrounded by a sphere of large radius r, the power which is transported through an element $dS = rd\theta\cdot r\sin\theta d\varphi$ of surface is

$$Pdz = Pr^2 d\theta\sin\theta d\varphi$$

The total power which goes through the sphere is

$$W = \frac{c}{4\pi}\left(\frac{\omega}{c^2}\right)^2(Il)^2\cos^2\omega\left(t-\frac{r}{c}\right)\int_0^{2\pi}d\varphi\int_0^{\pi}\sin^3\theta d\theta$$

$$= \frac{2c}{3}\left(\frac{\omega l}{c^2}I_0\right)^2\cos^2\omega\left(t-\frac{r}{c}\right) \tag{61}$$

This is a pulsating quantity which is always greater than zero. The average value of

$$\cos^2\omega\left(t-\frac{r}{c}\right)$$

per cycle, also per unit of time, is

$$\frac{1}{2\pi}\int_0^{2\pi}\cos^2 x dx = 1/2$$

consequently, the average value of W is

$$\overline{W} = \frac{1}{3c}\left(\frac{l\omega}{c}\right)^2 I_0^2 = \frac{1}{3c}\left(\frac{2\pi l}{\lambda}\right)^2 I_0^2 \tag{62}$$

This is the power which goes through the surface of any sphere, or for that matter, any closed surface around the radiator.

The law of conservation of energy demands that equal power be delivered to the radiator. In order that this may be the case, the current at some point or points of the radiator must flow against an electromotive force which has an inphase component. The value of this counterelectromotive force is proportional to the current, and its inphase component may be represented by the product of current times resistance. Resistance of this nature is usually called radiation resistance. The value of this resistance may be calculated readily when the power W radiated by the radiator is known. If I_0 is the peak value of the current, the rms is $I_0/\sqrt{2}$, and the power delivered by the current into a resistance R is $R(I_0/\sqrt{2})^2$. This power must be equal to the radiated power $\overline{W}$. Thus we may write

$$\left(R\frac{I_0}{\sqrt{2}}\right)^2 = \overline{W} = \frac{1}{3}\frac{1}{c}\left(\frac{2\pi l}{\lambda}\right)^2 I_0^2$$

$$R = \frac{2}{3}\frac{1}{c}\left(\frac{2\pi l}{\lambda}\right)^2 \text{ in electrostatic units}$$

Since one electrostatic unit $= 9\times10^{11}$ ohms and $c = 3\times10^{10}$ it follows that

$$R = \frac{60}{3}\times\left(\frac{2\pi l}{\lambda}\right)^2 = 80\pi^2\left(\frac{l}{\lambda}\right)^2 \text{ ohms}$$

In order to illustrate some additional features of the method, it will be applied to the case of a thin wire a half wave length long. In this case it is again necessary to assume the distribution of current along the wire. When the wire is very thin, experiments show that the current distribution is very nearly sinusoidal, so that current I at any point along the half-wave is

$$I = I_0\sin k\zeta\cdot\sin\omega t$$

From the equation of continuity

$$\frac{\partial I}{\partial\zeta} + \frac{\partial\bar{\rho}}{\partial t} = 0$$

It follows that the charge density $\bar{\rho}$ (charge per unit length) is given by

$$\bar{\rho} = -\frac{k}{\omega}I_0\cos k\zeta\cdot\cos\omega t$$

When the half-wave wire is placed along the ζ axis with one end of the wire at the origin of co-ordinates, the

components of the vector potential are

$$A_z=\frac{1}{c}\int_0^l \frac{I_0 \sin kz \cdot \sin \omega\left(t-\frac{r}{c}\right)}{r}dz$$

$$A_x=0 \qquad A_y=0$$

The scalar potential is

$$V=\frac{1}{c}\int_0^l -\frac{kI_0}{\omega}\frac{\cos kz \cdot \cos \omega\left(t-\frac{r}{c}\right)}{r}dz$$

These integrations are fairly lengthy and are not of much interest.[6] They will, therefore, be omitted. The components of H are

$$H_r=0, \quad H_\varphi=0,$$

$$H_\theta=\frac{I_0}{cr \sin \theta}\left\{\sin \omega\left(t-\frac{r_1}{c}\right)-\sin \omega\left(t-\frac{r_2}{c}\right)\right\}$$

in which r_1 and r_2 are the distances from the two ends of the wire to the point at which H is observed. This equation, as well as the companion equations for the components of E, is valid up to the surface of the wire. At large distances from the wire $E_r=0$ and

$$E_\theta=H_\varphi=\frac{2I_0}{rc}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

The total radiated power is calculated as in the previous example

$$P=\frac{c}{4\pi}\times\frac{1}{2}\times\int_0^{2\pi}d\varphi\int_0^{\pi}\left[\frac{2I_0}{rc}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]^2 r^2 \sin\theta\, d\theta$$

$$=\frac{I_0^2}{c}\ (1.22)$$

The radiation resistance R_0 is found by equating

$$R_0\left(\frac{I_0}{\sqrt{2}}\right)^2=P=\frac{I_0^2}{c}\ (1.22)$$

from which

$$R_0=\frac{1}{c}\times 2\times 1.22=30\times 2\times 1.22=73.5 \text{ ohms}$$

This radiation resistance is with reference to the current at the center of the half-wave wire. It is sometimes convenient to use as reference current I_1 at some other point $Z=Z_1$ along the wire. The radiation resistance R_1 with reference to this current must be such that

$$\left(\frac{I_1}{\sqrt{2}}\right)^2 R_1=\left(\frac{I_0}{\sqrt{2}}\right)^2 R_0$$

MODIFICATION OF METHOD 1

Some authors prefer to express all components of H and E in terms of one single vector Π which is called the Hertzian (radiation) vector. This procedure is substantially equivalent to method 1 as explained on the preceding pages.

Let current density $i=\partial P/\partial t$ then

$$A=\frac{1}{c}\int\int\int\frac{[i]}{r}dv$$

$$=\frac{1}{c}\int\int\int\frac{\left[\frac{\partial P}{\partial t}\right]}{r}dv$$

$$=\frac{1}{c}\frac{\partial}{\partial t}\int\int\int\frac{[P]}{r}dv$$

$$=\frac{1}{c}\frac{\partial \Pi}{\partial t}$$

where

$$\Pi=\int\int\int\frac{[P]}{r}dv \qquad (63)$$

$$H=\text{curl } A=\frac{1}{c}\text{ curl}\left(\frac{\partial \Pi}{\partial t}\right) \qquad (64)$$

Since

$$\text{div } A+\frac{1}{c}\frac{\partial V}{\partial t}=0 \qquad (42)$$

$$\frac{\partial}{\partial t}\left(\text{div }\frac{1}{c}\Pi\right)+\frac{1}{c}\frac{\partial V}{\partial t}=0$$

and

$$V=-c\text{ div}\left(\frac{1}{c}\Pi\right)+\psi(x, y, z)$$

Function $\psi(x, y, z)$ is independent of time and represents the potential of static charges. When there are no static charges

$$E=-\frac{1}{c^2}\frac{\partial^2 \Pi}{\partial t^2}+\text{grad (div }\Pi) \qquad (65)$$

This procedure avoids the necessity of solving the equation of continuity for ρ and then calculating the scalar potential V. The equation of continuity is solved indirectly and once and for all when the value of V is expressed in terms of Π by solving

$$\text{div } A+\frac{1}{c}\frac{\partial V}{\partial t}=0$$

which is substantially equivalent to the continuity equation 34.

The second part of this article discussing method 2 is scheduled to appear in a subsequent issue.

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INSTITUTE ACTIVITIES

Officers for 1943–44 Announced at Cleveland Meeting

Officers of the Institute for the year beginning August 1, 1943, were announced in the report of the committee of tellers presented at the annual meeting during the recent national technical meeting at Cleveland, Ohio. The new officers are:

President: Nevin E. Funk, vice-president in charge of engineering, Philadelphia (Pa.) Electric Company.

Vice-Presidents: W. E. Wickenden, president of the Case School of Applied Science, Cleveland, Ohio (District 2, Middle Eastern); C. W. Ricker, head of the school of electrical engineering, Tulane University, New Orleans, La. (District 4, Southern); L. A. Bingham, assistant professor in electrical engineering, University of Nebraska, Lincoln (District 6, North Central); W. J. Gilson, general manager, Eastern Power Devices, Ltd., Toronto, Ont. (District 10, Canada); J. M. Gaylord, chief electrical engineer, Metropolitan Water District of Southern California, Los Angeles (District 8, Pacific).

Directors: S. H. Mortensen, chief electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; C. W. Mier, engineer, Southwestern Bell Telephone Company, Dallas, Tex.; C. M. Laffoon, engineering manager of the a-c generator engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. (re-elected).

Treasurer: W. I. Slichter, professor emeritus of electrical engineering, Columbia University, New York, N. Y. (re-elected).

The board of directors for the administrative year beginning August 1, 1943, will consist of the foregoing elected officers and the following holdover officers:

H. S. Osborne, New York, N. Y. (*retiring president*); D. C. Prince, Schenectady, N. Y. (*junior past president*); K. B. McEachron, Pittsfield, Mass.; C. R. Jones, New York, N. Y.; A. G. Dewars, Minneapolis, Minn.; E. T. Mahood, Kansas City, Mo.; E. W. Schilling, Bozeman, Mont. (*vice-presidents*); T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa,; R. G. Warner, New Haven, Conn.; L. R. Gamble, Spokane, Wash.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; K. L. Hansen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; L. R. Smith, Newark, N. J. (*directors*).

A detailed report of the national technical meeting at Cleveland is scheduled to appear in the August issue.

Future AIEE Meetings

National Technical Meeting
Salt Lake City, Utah, September 2–4, 1943

Southern District Meeting
Roanoke, Va., November 16–18, 1943

Revised Standards Approved at Executive Committee Meeting

The executive committee of the American Institute of Electrical Engineers met at Institute headquarters, New York, May 27, 1943, in lieu of the regular May meeting of the board of directors.

Present: Members of the committee—Chairman H. S. Osborne and C. R. Jones, New York, N. Y.; David C. Prince and W. I. Slichter, Schenectady, N. Y.; R. W. Sorensen, Pasadena, Calif.; R. G. Warner, New Haven, Conn. Other members of the board of directors—Vice-President C. A. Powel, East Pittsburgh, Pa.; Directors T. G. LeClair, Chicago, Ill., and W. Ralph Smith, Newark, N. J. By invitation—Vice-Chairman George R. Canning of the Cleveland national technical meeting committee for the period of discussion of plans for that meeting, and National Secretary H. H. Henline.

Executive committee actions on applications were reported and confirmed, as follows: As of March 22, 1943, 8 applicants were transferred to the grade of Fellow and 35 to the grade of Member, 41 applicants were elected to the grade of Member and 195 to the grade of Associate, and 286 Students were enrolled; as of April 9, 1943, 4 applicants were transferred to the grade of Fellow and 19 to the grade of Member, 434 applicants were elected to the grade of Associate, and 68 Students were enrolled.

Also reported and approved was approval by the executive committee, upon recommendation of the standards committee, of: Revision of the American Standard, "Letter Symbols for Heat and Thermodynamics Including Heat Flow," developed by sectional committee Z10 on Letter Symbols and Abbreviations for Science and Engineering, to supersede the American Tentative Standard of the same name published in 1931; War Emergency Modification of AIEE Standard 45, "Recommended Practice for Electrical Installations on Shipboard," prepared by the committee on marine transportation, for publication as a supplement to Standard 45 to apply for the war emergency only.

Recommendations adopted by the board of examiners at meetings on February 18, March 18, April 22, and May 20, 1943, were approved. The following actions were taken upon recommendation of the board of examiners: 6 applicants were transferred and one was re-elected to the grade of Fellow, 29 applicants were transferred and 49 were elected to the grade of Member, 310 were elected to the grade of Associate, and 312 Students were enrolled.

Disbursements were reported by the finance committee, and approved by the executive committee, as follows: February, $27,400.96; March, $32,797.61; April, $25,264.77; May, $28,328.00.

The annual report of the national treasurer for the fiscal year which ended April 30, 1943, was presented and accepted.

Approval was given for presentation at the annual meeting of the Institute on June 22 of the annual report of the board of directors for the fiscal year which ended April 30, 1943, prepared under the direction of the national secretary.

Dates and location of the Southern District technical meeting previously authorized to be held in Virginia in the fall of 1943 were approved, namely: November 16–18, Roanoke, Va. Decision was made to schedule a national technical meeting in New York, N. Y., January 24–28, 1944, and a national technical meeting in St. Louis, June 26–30, 1944.

Upon recommendation of the Sections committee, the following actions were taken:

A Dayton section was authorized, with territory comprising Preble, Montgomery, and Green Counties, Ohio (released by the Cincinnati Section), and Darke, Miami, Clark, Champaign, and Shelby Counties (released by the Columbus Section).

Unassigned counties in Nevada were assigned to Sections, as follows: Humboldt, Pershing, Churchill, Lander, and Esmeralda Counties to the San Francisco Section; Nye and Lincoln Counties to the Los Angeles Section; Elko, Eureka, and Whitepine Counties to the Utah Section.

The name of the Saskatchewan Section was changed to Midwestern Canada Section, its territory to include the provinces of Manitoba and Alberta.

Members in Ottawa and vicinity were transferred from the Toronto Section to the Montreal Section, and that portion of the Province of Ontario east of a line drawn from Ottawa to Cornwall, formerly in the Toronto Section, was added to the territory of the Montreal Section.

The executive committee confirmed the endorsement by the committee on research of application to the Engineering Foundation for a grant for the year beginning October 1, 1943, to the Welding Research Council, for which the AIEE and the American Welding Society are joint sponsors.

The following actions were taken upon recommendation of the standards committee: Approved appointment of Herman Koenig as an AIEE representative on the sectional committee on electrical measuring instruments, C69, and D. E. Renshaw as representative and A. C. Muir as alternate on the sectional committee on safety rules for installing and using electrical equipment in coal mines, M2; approved for immediate publication a revision of AIEE Standard 19, "Oil Circuit Breakers," submitted by the committee on protective devices.

In accordance with section 37 of the constitution, H. H. Henline was reap-

pointed national secretary of the Institute for the administrative year beginning August 1, 1943.

Approval was given to the publication by the Engineers' Council for Profesional Development of a pamphlet outlining a plan of co-operation between the Engineering Council for Professional Development and local groups of the participating societies to further the objectives of ECPD.

The appointment by the president of the following committee of tellers to canvass and report on the ballots cast for the election of Institute officers was confirmed: L. B. Bogan, *chairman;* R. C. Darrow, M. L. Gardner, H. I. Perry, C. E. Scholz, Norman S. Spatz, and Otto E. Stamm.

F. Malcolm Farmer was nominated for re-election by the board of trustees of United Engineering Trustees, Inc., to the Engineering Foundation Board for the four-year term beginning in October 1943. H. B. Gear was reappointed a representative of the Institute on the Washington Award Commission for the two-year term beginning June 1, 1943.

Other matters were discussed, reference to which may be found in this or future issues of *Electrical Engineering*.

Contents of June 1943 Supplement Announced

The five remaining technical papers presented at the 1943 AIEE national winter technical meeting and not published in the monthly *Transactions* sections of *Electrical Engineering* will appear in the June 1943 "Supplement to Electrical Engineering—Transactions Section." The discussions of these papers and the discussions of the technical papers published in the January–June monthly sections will be included in the supplement. This will complete the publication of papers and discussions presented at the New York winter meeting.

Copies of the supplement will be mailed shortly to those who entered advance orders. Others may obtain copies at 50 cents each from the AIEE order department, 33 West 39th Street, New York 18, N. Y., as long as the limited supply lasts.

The following papers which have been abstracted in *Electrical Engineering* will be printed in the supplement:

43-23—Electrical Stability of Electrical Insulating Oils Under Limited Oxidation; *J. C. Balsbaugh (M '35), A. B. Assaf.* Abstracted in January 1943 issue, page 27.

43-12—Impulse and 60-Cycle Characteristics of Driven Grounds, III—Effect of Lead in Ground Installations; *P. L. Bellaschi (F '40), R. E. Armington (A '42).* Abstracted in January 1943 issue, page 30.

43-32—An Improved Axial Air-Blast Interrupter for Severe Operating Duty; *P. L. Taylor (A '27), H. W. Martin (A '40).* Abstracted in the January 1943 issue, page 32.

43-39—Staged-Fault Tests of Relaying and Stability on Kansas–Nebraska 270-Mile 154-Kv Interconnection; *C. W. Minard, R. B. Gow (A '35), W. A. Wolfe (M '30), E. A. Sunnans.* Abstracted in January 1943 nue, page 33.

43-46—Field Disturbances Produced by Lightning; *G. D. McCann (A '38), D. E. Morgan (A '41).*

National and District Paper Prizes Awarded

The awards of the national prizes for the best papers presented during 1942 have been announced by P. L. Alger, chairman of the AIEE committee on award of Institute prizes. In choosing the papers the award committee had the assistance of the chairman of the technical committees in the various fields involved. As in 1940 and 1941 no award was made in the field of public relations and education because of lack of eligible papers in those categories. The prizes were presented, June 22, 1943, at the national technical meeting of the Institute at Cleveland, Ohio.

The final selections of the committee were:

Best Paper in Engineering Practice: Prize awarded to Herman Halperin (M '26) of the Commonwealth Edison Company, Chicago, Ill., for his paper, "Load Ratings of Cables—II," presented at the 1942 summer convention, June 22–26, and published in the 1942 *Transactions*, pages 930–42. Honorable mention was awarded to E. L. Harder (M '41), E. H. Klemmer (A '42), W. K. Sonnemann (M '43), and E. C. Wentz (M '42), of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for their paper "Linear Couplers for Bus Protection," presented at the 1942 winter convention, January 26–30, and published in the 1942 *Transactions*, pages 241–48.

Best Paper in Theory and Research: Prize awarded to C. F. Wagner (F '40), G. D. McCann (A '38), and C. M. Lear, of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for their paper "Shielding of Substations," presented at the 1942 winter convention, January 26–30, and published in the 1942 *Transactions*, pages 96–100. Honorable mention was awarded to R. C. Van Sickle (M '37) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for his paper "Transient Recovery Voltages and Circuit-Breaker Performance," presented at the 1942 summer convention, June 22–26, and published in the 1942 *Transactions*, pages 804–13.

Initial Paper: Prize awarded to T. D. Graybeal (A '38) of the University of California, Berkeley, for his paper, "Steady-State Theory of the Amplidyne Generator," presented at the 1942 summer convention, June 22–26, and published in the 1942 *Transactions*, pages 750–6. Honorable mention was awarded to D. E. Trucksess (M '40) of the Bell Telephone Laboratories, New York, N. Y., for his paper, "Regulated Rectifiers in Telephone Offices," presented at the 1942 summer convention, June 22–26, and published in the 1942 *Transactions*, pages 613–17.

Branch Paper: Prize awarded to Hugh Fleming (Enrolled Student) of Oregon State College, Corvallis, for his paper, "A Study of the Effect of High-Frequency Fields on Micro-Organisms" presented at a joint meeting of the Portland (Oreg.) Section and the Oregon State College Branch, May 16, 1942.

DISTRICT PRIZES

District prizes for AIEE papers have been announced by six Districts. The awards are for papers presented during 1942, except Branch papers, which were presented during the academic year ending June 30, 1942.

District 1

Prize for best paper was awarded to A. G. Conrad (M '40), Felix Zweig (A '42), and J. G. Clarke (A '41) for their paper, "Theory of the Brush-Shifting A-C Motor, Part IV," presented at the North Eastern District meeting, Schenectady, N. Y., April 29–May 1, 1942.

Prize for graduate student paper was awarded to B. P. Brown for his paper, "A New Transmitting Antenna for High-Definition Television," presented at the North Eastern District student convention, Rochester, N. Y., May 2, 1941.

Prize for Branch paper was awarded to S. B. Cohn (A '43) for his paper, "A New Automatic Radio Direction Finder," presented at the North Eastern District student convention, Schenectady, N. Y., May 1, 1942.

District 2

Prize for Branch paper was awarded to E. L. Bradford (A '43) for his paper, "Lightning Arresters for Distribution Systems," presented at a meeting of the Johns Hopkins University Branch, Baltimore, Md., December 11, 1941.

District 5

Prize for Branch paper was awarded to Sol London (A '43) for his paper, "Applications of Dimensional Analysis," presented at a meeting of the University of Iowa Branch, Iowa City, November 15, 1941.

District 6

Prize for Branch paper was awarded to Edward Edison (A '43) for his paper, "The Operation of Three-Phase Motors From a Single-Phase Supply," presented at the 15th annual District conference on student activities, Colorado State College, Fort Collins, April 17–18, 1942.

District 7

Prize for Branch paper was awarded to F. A. Collins (Enrolled Student) for his paper, "Separation of Core Losses," presented at a joint meeting of the Houston Section, Rice Institute Branch, and Texas A. & M. College Branch, March 27, 1942.

District 10

Prize for best paper was awarded to D. M. Farnham (M '42) and O. W. Titus (M '36) for their paper, "Design, Manufacture, and Installation of 120-Kv Oil-Filled Cables in Canada," presented at the Pacific Coast convention, Vancouver, B. C., September 9–11, 1942.

Prize for initial paper was awarded to W. R. Way (M '42) for his paper, "Power System Interconnection in Quebec," presented at the Pacific Coast conventions Vancouver, B. C., September 9–11, 1942.

Prize for Branch paper was awarded to H. T. Stevinson (Enrolled Student) for his paper, "Lightning and the Broadcast Transmitter," presented at a meeting of the University of Alberta Branch, Edmonton, March 16, 1942.

Board of Directors Report Omitted From July Issue

Because of governmental limitations on the use of paper the annual report of the AIEE board of directors is not being published in the July issue of *Electrical Engineering* as has been the policy of recent years. However most of the Institute activities reviewed in the report have been reported in *Electrical Engineering* throughout the year.

Members who wish may obtain copies of the 16-page board of directors report from AIEE headquarters, 33 West 39th Street, New York 18, N. Y.

District Numbers Requested for New Addresses

By a recent regulation of the Post Office Department persons living in approximately 175 of the principal cities in the United States have had district numbers added to their addresses. To assist us in meeting the post office ruling, members living in these cities are requested to indicate their Post Office district numbers when informing headquarters of changes of address. Thus for the future the address of AIEE headquarters will read: 33 West 39th Street, New York 18, N. Y.

Additions to List of Members for Life

Membership for life is granted by the AIEE to members who either have paid

annual dues for 35 years, or have reached the age of 70 and paid dues for 30 years. A list of those who have become members for life during the preceding year is published annually in *Electrical Engineering*. Institute members who have attained this status since publication of the last list in July 1942, are:

H. G. Acres
E. H. Acton
H. V. Allen
R. J. Andrus
J. C. Armor
F. R. Bacon
B. F. Bailey
C. E. Banta
M. Barnert
J. T. Barron
W. O. Batchelder
C. R. Beardsley
J. D. G. Beaubien
M. Berthold
P. S. Biegler
L. S. Billau
E. H. Billipp
J. E. Boesch
F. Borch
W. S. Bourlier
F. K. Brainard
A. T. Childs
C. V. Christie
M. H. Clapp
C. L. Collens
T. R. Cook
C. P. Cooper
H. H. Cox
L. P. Crecelius
F. B. Crosby
F. Daugherty
C. M. Davis
J. G. De Remer
L. E. Dickinson
W. N. Dickinson
C. R. Dooley
D. C. Durland
C. F. Elwell
W. G. B. Euler
H. W. Evans
L. Evans
F. H. Froehlich
J. R. W. Gardam
H. O. Garman
H. Gebhart
V. E. Goodwin
E. W. Gough
S. H. Grauten
H. G. Hake
A. A. Hall
R. H. Halpenny
I. E. Hansen
H. C. Hawkins
C. A. Heinze
F. K. T. Hepburn
J. H. Hertner
H. Hertz
A. Hertz
G. A. Hodge
F. D. Hoge
F. H. Hollister
A. J. Horton
H. W. Hough
H. G. Howard
L. S. Ickis
B. G. Jamieson
A. J. Jones
A. L. Jones
F. P. Jones
F. L. Kemp
J. L. Kilpatrick
C. L. Kinsole
H. T. Kohlhaas
W. C. Lane
G. F. Leake
A. W. Lee
E. H. Le Tourneau
H. O. Lewis
L. V. Lewis
J. F. Lincoln
J. J. Linebaugh
W. MacLachlan
C. MacMillan
C. A. Mally
R. H. Manahan
H. L. Martien
J. M. S. Maxwell
W. R. McCann
J. R. McFarlin
E. G. Merrick
G. S. Merrill
J. F. Meyer
G. Meager
C. B. Mirick
R. F. Monges
G. H. Morse
R. C. Muir
N. J. Neall
L. J. Newman
G. Pace
J. C. Peet
A. S. Peters
J. R. Price
F. H. Pritchard
A. Raynsford
N. Read
W. A. Reece
C. R. Riker
H. Rowe
F. O. Runyon
C. P. Schroeder
I. H. Sclater
N. Shute
J. E. Smith
R. W. Sorensen
W. B. Stelzner
J. C. Stephens
F. Stern
H. R. Summerhayes
A. A. Thompson
A. W. Thompson
P. Thut
R. H. Tillman
J. H. Tracy
M. O. Troy
E. E. Turkington
W. L. Upson
L. B. Vanderbilt
S. S. Watkins
J. W. Watson
L. W. Webb
F. Wenner
A. Westman
J. M. Whalen
W. E. Wickenden
F. W. Willey
L. R. Woodhull
J. L. Woodrow
F. B. Wright
W. Wurth
R. M. Wynn
A. V. Youens
C. R. Young
W. A. Young

BRANCH

Vanderbilt University Forms AIEE Branch

An AIEE Student Branch authorized at the January meeting of the AIEE board of directors was organized recently at Vanderbilt University, Nashville, Tenn. This is the 125th Branch to be organized.

Officers who will serve until December 31, 1943 were elected on March 22. The enrolled students elected are:

Chairman—Henry M. Bailey.
Vice-chairman—James E. Atkinson.
Secretary-treasurer—Fred T. Ragan, Jr.

Professor S. R. Schealer (M '23) was elected Branch counselor.

SECTION

Fourth Canadian Section Organized at Montreal

The fourth AIEE Canadian Section and the fifth Section to be formed outside the United States held its organization meeting April 16, 1943, at Montreal, Que. Formation of the new Section had been authorized at the January meeting of the AIEE board of directors.

The following officers were elected to serve until July 31, 1943:

Chairman—Frederick Krug (F '36) general manager, Montreal (Que.) Engineering Company.

Secretary-treasurer—D. M. Farnham (M '42) assistant distribution engineer, Montreal (Que.) Light, Heat and Power Consolidated.

Chairman program committee—J. J. Dougherty (A '30) Eastern Power Devices, Ltd., Montreal, Que.

Executive committee—J. L. Clarke (M '30) transmission engineer, Bell Telephone Company of Canada, Montreal, Que.; F. L. Lawton (M '36) assistant chief engineer, Aluminum Company of Canada, Montreal, Que.; N. L. Morgan (A '17) cable engineer, Northern Electric Company, Ltd., Montreal, Que.; and G. A. Wallace (A '20) assistant professor of electrical engineering, McGill University, Montreal, Que.

At the meeting, District 10 initial paper prize was presented to W. R. Way (M '42) for his paper, "Power-System Interconnection in Quebec," and the District best paper prize to D. M. Farnham and O. W. Titus (M '36) for their paper, "Design, Manufacture, and Installation of 120-Kv Oil-Filled Cables in Canada," both presented at the Pacific Coast convention in September 1942.

ABSTRACTS

TECHNICAL PAPERS previewed in this section were presented at the AIEE national technical meeting, Cleveland, Ohio, June 21–25, 1943, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail Orders will be filled AS PAMPHLETS BECOME AVAILABLE

Air Transportation

43-123—Aircraft Electric-Power-Supply System; *J. E. Yarmack (M '42).* *15 cents.* Large aircraft are now being equipped with electrically powered accessories, necessitating an electric plant of far greater size than has been available to date. Indications are that future electric load will be on the increase. One possible way of coping with its growth is to generate alternating current in the same manner as conventional direct current and then either to transformer or to convert, or both, by means of separately installed transformers and rectifiers. The electro-physical laboratory of Chrysler Corporation, under the direction of G. C. Goode and F. J. Finkenauer, Jr., together with the author, have designed and built several a-c–d-c aircraft systems utilizing alternators, Selenium rectifiers, and transformers. This paper contains a brief summary of factors entering into the design and construction of these component units and represents a current report on development and test work now in progress.

43-124—Characteristics and Applications of the General Electric Selenium-Rectifier Cells. *By Edgar A. Harty (M '36).* *20 cents.* This paper describes the d-c and a-c characteristics of a new type of selenium-rectifier cell as developed by the General Electric Company. Complete design information is given to enable engineers who are not rectifier specialists to apply these cells to rectifier circuits. Data are shown in tabulated as well as curve form to permit estimating voltages and current input and output values. Single- and three-phase circuits are discussed. Information on life, aging, efficiency, and temperature characteristics is given. Finally an example is worked out using the data contained in this paper.

43-125—Fundamental Principles of Amplidyne Applications; *F. E. Crever (A '27).* *15 cents.* The amplidyne generator has been applied widely and is recognized as an important device in the electrical industry. Since it is used primarily as a power amplifier in regulating systems, the requirements of an amplifier for this use are analyzed and the characteristics of the amplidyne generator are compared in this paper with these requirements. Because of the large number of distinct windings of the amplidyne, it is desirable to follow a consistent practice in terminal markings and polarities. Proposals for this purpose are outlined in the paper, and typical values of amplification for different output ratings are given. Service experience and an application typifying the use of the amplidyne are discussed, so that the reader may become familiar with the device and its uses.

43-126—Design Relationships for D-C Generators for Use in Aircraft; *S. R. Bergman (A '04).* *15 cents.* The electric power in aircraft is based on a 24-volt system. It consists of d-c generators in conjunction with a 24-volt storage battery. The generators are mounted on the main engines, and in large Navy planes there are, in addition, generators driven by auxiliary engines. Certain requirements in both electrical and mechanical design are imposed by the fact that a plane is flying through varying altitudes, resulting in changing atmospheric conditions, such as rarefication, low temperature, and ioniza-

tion. Other unusual conditions are created from the motion of the plane setting up accelerating forces on the generator, as well as mechanical forces caused by engine vibrations. Because of important features such as commutation, voltage regulation, cooling, driving means, and light weight, special and unusual methods must be employed. In solving these problems the most perfect methods known in the art of building d-c machines must be resorted to. The paper lays particular stress on the use of compensation.

43-127—Aircraft Inverter Construction; *C. T. Button* (*A '26*). *15 cents.* The paper discusses design requirements of aircraft inverters used for conversion of direct current at 27.5 volts to 400 cycles single- and three-phase alternating current. The 400-cycle output is used for operation of instruments, radio compass, fluorescent lighting, automatic pilots, and so forth. Various basic types of rotary inverters are listed, with relative merits and characteristics given in general terms. The desired features of design and operation are given, of which minimum weight and high efficiency are most important. Different types of control accessories for obtaining required voltage and frequency control and freedom from radio interference are described.

43-128—Aircraft Circuit Breakers; *C. W. Kuhn* (*F '36*). *15 cents.* The electric system of military aircraft contributes largely to their effectiveness. Any part of the electric system may be damaged in battle. Airplane-type circuit breakers keep, as much of the system as possible, available at all times. They must meet the special requirements of aircraft service. Minimum size and weight are of unusual importance. This is obtained by combining circuit protection with switch or contactor. The principle function of both manual- and remote-control circuit breakers is to provide short-circuit protection. There is some question as to the desirability of motor protection for military aircraft. Many motor functions are vital to the operation of the aircraft, and it may be better to operate the motor to destruction rather than to stop at a safe temperature or load value. Where motor overload protection is desired, it is necessary to correlate circuit-breaker and motor characteristics. Both manual- and remote-control circuit breakers can be made to provide for holding the circuit closed in emergency to "force" the motor or other equipment.

43-129—Principles of Aircraft Electric-Motor Protection; *V. G. Vaughan. 15 cents.* This paper discusses the steps to be followed in arriving at the proper kind of inherent overheat protection for aircraft electric motors. There is brought out the great range of ambient temperatures encountered. It stresses the need of protecting at temperatures just short of the destructive temperature. Overprotection should be avoided. It is better to have an occasional burn-out than to limit the output of all motors. Locked rotor protection only should be avoided, for when a motor protector has been applied for locked rotor protection only, then at running loads the motor may be underprotected or overprotected. All available output of the motor with complete protection for all conditions can only be obtained when the protector application is engineered to meet the various ambients and load conditions which may be encountered in aircraft flying in any part of the world.

43-130—Manual Switches for Aircraft; *R. A. Millermaster* (*M '34*). *15 cents.* Manual switches for aircraft are applied in a rapidly expanding and changing field where rapid obsolescence of past practices is the rule. The switch manufacturer cannot keep informed of all utilization equipment changes. Experience has proved it preferable that the manufacturer make available complete performance data on his switches, so that the aircraft manufacturer can himself match the control means to the utilization device. To provide usable performance data, the switch manufacturer must include measures of the switch capacity to establish, maintain, and interrupt a circuit, modifying each rating in terms of the load characteristics—such as inrush values, inductance, voltage, and current. He must also include performance data related to the chemical and physical surroundings in which the switch will function, and these will include ambient temperature, humidity, chemical atmosphere or sprays, accelerations, and air pressure. Tests to determine these are described.

43-131—Aircraft Contactors; *F. J. Russell* (*M '37*) and *A. P. Charbonneau. 15 cents.* Design of contactors for use in aircraft follows principles developed for commercial contactors, but many new problems are encountered. An analysis of the operation of the contacts aids in determining the work curve and the pull required from the magnet. With these factors determined, the design may be made to provide the greatest utilization of material and space, very important consideration on all devices used on aircraft. Circuit requirements demand contactors having a range of ratings up to 200 amperes continuous duty and various combinations of normally open and normally closed contacts. A line of contactors embracing these combinations has been developed embodying the features required for aircraft service.

43-132—Radio-Noise Filters Applied to Aircraft; *C. W. Frick* (*A '19*), *and S. W. Zimmerman* (*M '40*). *20 cents.* Performance characteristics of radio-noise suppression devices including capacitors as well as filters are described. Available filters for use in aircraft are described as to current and voltage ratings, dimensions, weight, suppression ratios, and other features. An elementary case of a power circuit to which suppression is applied and a paralleling radio system are discussed, for the purpose of bringing out some important considerations in the selection, installation, and testing of suppression devices, as well as some of the terms commonly used. Conditions under which each of the two suppression devices, filters and capacitors, may be used effectively are pointed out. Measurements which check the performance of suppressors on actual equipment are described. Measurements are also described which are made on an accepted laboratory circuit for rating purposes and for checking the product of the factory. The laboratory circuit is analyzed in an appendix.

Electrical Machinery

43-109—Interim Report on Overloading Current-Limiting Reactors; *transformer subcommittee of committee on electrical machinery. 15 cents.* The "Interim Report on Guides for Overloading Transformers and Voltage Regulators," which was presented at the AIEE summer convention, June 22 1942, and was published in *AIEE Transactions*, volume 61, 1942, September section, pages 692–4, gave information on the overloading of all types of transformers and of voltage regulators. An additional report, specifically applicable to the operation of distribution transformers, has already been issued and is soon to be published. A third report, covering the related problem of overloading current-limiting reactors, is now being issued for use in conjunction with these two reports. Recommended overloads and maximum operating temperatures are presented for oil-immersed and dry-type reactors installed in the open or enclosed in compartments.

PERSONAL • • • •

P. M. Gee (A '11, M '21) division engineer, Consolidated Edison Company of New York (N. Y.), Inc., has retired. He received his bachelor of science degree from Clemson College in 1909 and then spent one year in the student engineering course of the General Electric Company, Pittsfield, Mass. From 1910 to 1912 he worked in the testing department at Schenectady, N. Y. In 1912 he became assistant chief inspector of assembled switchboards and in 1913 was made switchboard designing engineer. From 1915 to 1917 he worked as designer for Stone and Webster, Boston, Mass. He commenced his 26-year association with the Edison system in 1917 as foreman for the Brooklyn (N. Y.) Edison Company. In 1922 he was made chief electrical draftsman and in 1923 assistant engineer. He was appointed division engineer in 1929 and, as such, was transferred to the Consolidated Edison company's inside plant department in 1936.

C. F. Wagner (A '20, F '40) manager of the central station engineering department Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1942 national best paper prize

C. F. Wagner

T. D. Graybeal

Herman Halperin

G. D. McCann

in theory and research as coauthor of the paper, "Shielding of Substations." He received the degree of bachelor of science from the Carnegie Institute of Technology in 1917. In 1918 he entered the employ of the Westinghouse company as research assistant in the materials and processes engineering department. He was transferred to the porcelain insulators and transmission engineering department in 1924. In that department he was occupied chiefly with stability problems directed toward improving transmission. In 1938 he was appointed consulting transmission engineer and in 1941 manager of the central station engineering department. Previously he was awarded the national best paper prize in engineering practice in 1938, as well as the George Montefiore award in 1929. Numerous patents have been issued to him. He has served on the AIEE committee on power transmission and distribution from 1930 to 1932 and again from 1937 to 1943.

T. D. Graybeal (A '38) instructor in electrical engineering, University of California, Berkeley, has been awarded the 1942 national best paper prize for his initial paper, "Steady-State Theory of the Amplidyne Generator." He was graduated from the University of California in 1937 with the degree of bachelor of science in electrical engineering. In 1939 he received the degree of master of science from Massachusetts Institute of Technology and in 1941 the degree of doctor of engineering from Yale University. From 1937 to 1939 he was research assistant at Massachusetts Institute of Technology, Cambridge. In 1939 he became assistant in instruction at Yale University, New Haven, Conn., and in 1941 was appointed instructor in electrical engineering at the University of California. He is a member of Tau Beta Pi.

Herman Halperin (A '21, M '26) assistant equipment and research engineer, Commonwealth Edison Company, Chicago, Ill., has been awarded the 1942 national best paper prize in engineering practice for his paper "Load Ratings of Cables—II." He was graduated from Cornell University in 1920 with the degree of mechanical engineer. During 1920 and 1921 he supervised electrical construction for the Union Gas and Electric Company, Cincinnati, Ohio. In 1921 he entered the employ of the Commonwealth Edison Company where he worked on miscellaneous problems connected with underground cable systems. In 1927 he became head of the company's technical division. He was named cable research engineer in 1933 and assistant equipment and research engineer in 1937. He has served on the AIEE committee on protective devices (1925–31, 1937–42), power transmission and distribution (1936–43), and research (1936–39).

G. D. McCann (A '38) transmission engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1942 national best paper prize in theory and research as coauthor of the paper, "Shielding of Substations." Mr. McCann received from the University of California the degrees of bachelor of science in 1934, master of science in 1935, and doctor of philosophy in 1939. In 1938 he entered the employ of the Westinghouse company as central station engineer. In 1941 he became transmission engineer. He is a member of Sigma Xi.

R. C. Van Sickle (A '33, M '37) circuit breaker and protective devices engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received honorable mention in the 1942 national prize award for the best paper in theory and research for his paper, "Transient Recovery Voltages and Circuit-Breaker Performance." He holds the degrees of mechanical engineer (1923) and electrical engineer (1924) from Cornell University and the degree of master of science from the University of Pittsburgh (1928). He has been associated with the Westinghouse company since 1924. After two years in the student course and the supply engineering department, he became circuit-breaker engineer. From 1928 to 1930 he was exchange and liason engineer for the Westinghouse company at the Siemens Schuckert Works, Berlin, Germany.

F. D. Egan (M '34) electrical superintendent, Bethlehem Steel Company, Lackawanna, N. Y., has been granted an indefinite leave of absence. A past president of the Association of Iron and Steel Engineers, he has been superintendent since 1923. **R. W. Graham** (A '18, M '31) formerly assistant superintendent, will succeed Mr. Egan. Mr. Graham, who was an instructor at Cornell University, Ithaca, N. Y., for three years, has been with the Bethlehem company since 1916. **T. O. Zittel** (A '34) formerly student engineer, will become assistant superintendent. He graduated from Rensselaer Polytechnic Institute in 1933 and was employed by the Bethlehem company in 1935.

E. C. Wentz (A '28, M '42) transformer design engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has received honorable mention in the 1942 prize award for the best paper in engineering practice as one of the coauthors of the paper, "Linear Couplers for Bus Protection." He holds the degrees of bachelor of science (1926) and electrical engineer (1939) from the University of Minnesota and that of master of science (1936) from the University of Pittsburgh. He has been employed by the Westinghouse company since 1926 and is a frequent contributor to electrical publications.

D. E. Trucksess (M '40) research engineer, power apparatus development department, Bell Telephone Laboratories, New York, N. Y., has received honorable mention in the 1942 national prize award for the best initial paper for his paper, "Regulated Rectifiers in Telephone Offices." A graduate of Pennsylvania State College, Mr. Trucksess has been engaged in electrical research at Bell laboratories since 1926. He is the author of numerous articles and holds several patents.

W. K. Sonneman (A '38, M '43) design engineer, Westinghouse Electric and Manufacturing Company, Newark, N. J., has received honorable mention in the 1942 national prize award for the best paper in engineering practice as one of the coauthors of the paper, "Linear Couplers for Bus Protection." He was graduated from the University of Texas in 1924 and worked as design engineer for the Westinghouse company until 1929. As switchboard designer he was employed by the Texas Power and Light Company, Dallas, from 1929 to

1932 and by the Texas State Highway Department from 1933 to 1935 as assistant in highway design and construction. He returned to the Westinghouse company in 1936.

E. L. Harder (A '30, M '41) central station engineer, Middle Atlantic district, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received honorable mention in the 1942 national prize award for best paper in engineering practice as one of the coauthors of the paper, "Linear Couplers for Bus Protection." He holds the degree of electrical engineer from Cornell University (1926) and that of master of science from the University of Pittsburgh (1930). He has been with the Westinghouse company since 1926 as student engineer, design engineer, and finally, central station engineer. Mr. Harder also received honorable mention in the 1939 national prize award.

W. S. Edsall (M '19) formerly assistant manager of the electrical department, Allis-Chalmers, Manufacturing Company, Boston, Mass., has been made manager of a newly combined swtichgear and control division of the company at Milwaukee, Wis. Mr. Edsall became associated with the Allis-Chalmers company in 1931 when the latter purchased Condit Electric Manufacturing Corporation of which he was a director. He then became sales manager for the Condit works and later of the switchgear division of the Allis-Chalmers company.

W. G. Willson (A '41) formerly manager, Phoenix (Ariz.) office, Westinghouse Electric and Manufacturing Company, has been named Los Angeles (Calif.) manager for that company. He entered the employ of the Westinghouse company in 1913 and had been Phoenix manager for 18 years. **H. S. Warren** (A '35) formerly of the central sales department, Los Angeles, Calif., will succeed Mr. Willson as manager of the Phoenix office. Mr. Warren joined the Westinghouse company at Los Angeles in 1922.

E. H. Klemmer (A '42) switchgear engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received honorable mention in the 1942 national prize award for the best paper in engineering practice as one of the coauthors of the paper, "Linear Couplers for Bus Protection." A 1925 graduate of the Carnegie Institute of Technology, Mr. Klemmer has been switchgear engineer with the Westinghouse company since 1929.

S. T. Fisher (M '43) formerly sales and development engineer, Northern Electric Company, Ltd., Montreal, Que., has been appointed assistant to the president of Rogers Radio Tubes, Ltd., and special products manager of Rogers Majestic, Ltd., Toronto, Ont. He had been associated with the Northern Electric Company since he received his bachelor of science degree from the University of Toronto in 1930.

C. N. Simpson (M '34) formerly general manager of the Gatineau Power Company, Ottawa, Ont., has been elected vice-president of that company. A graduate of the University of Toronto, Mr. Simpson joined the Gatineau company in 1926 as supervisor of the power developments on the Gatineau river. In 1929 he was appointed chief engineer and in 1935 general manager.

N. E. Funk (A '07, F '34) vice-president in charge of engineering, Philadelphia (Pa.) Electric Company, and new AIEE president-elect, recently received the honorary degree of doctor of engineering from Lehigh University. A fuller biography of Doctor Funk appears in *Electrical Engineering*, March 1943, page 127.

W. B. Schaffir (Enrolled Student) undergraduate at the Case School of Applied Science, Cleveland, Ohio, is the recipient of a $25 award for a paper submitted in the engineering undergraduate award and scholarship program of the James F. Lincoln Arc Welding Foundation.

A. S. Gray (A '41) vice-president of the Insulation Manufacturing Corporation, Chicago, Ill., has been appointed to the Built Up Mica Industrial Advisory Committee recently formed by the War Production Board.

H. J. van der Bijl (M '17) chairman of the Electricity Supply Commission, and chancellor of Pretoria University, Johannesburg, Transvaal, South Africa, is one of five scientists recently elected foreign associates of the National Academy of Sciences.

Delevan Haloran (A '32, M '32) formerly assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., has been commissioned a senior lieutenant in the United States Navy and is stationed at Savannah, Ga.

W. G. Vreeland (A '39) formerly junior engineer, Consolidated Edison Company of New York (N. Y.), Inc., has secured a wartime leave of absence to join E. H. Badger and Sons, Consulting Engineers, New York, N. Y.

W. D. Coolidge (A '10, M '34) vice-president and director of research, General Electric Company, Schenectady, N. Y., has been awarded the Order of Merit of Chile for his "many services to civilization."

J. L. Holton (A '30, M '37) formerly division engineer, New York and Queens Light and Power Company, Flushing, is now at the Eastman Kodak Company, New York, N. Y., on a wartime leave of absence.

L. W. Long (A '37) formerly factory sales engineer, Allis-Chalmers Manufacturing Company, Pittsburgh, Pa., has been appointed sales engineer in charge of mixed apparatus sales.

W. S. Lee, Jr. (A '30) formerly lieutenant commander, United States Navy, has been appointed commander and now heads the 15th Naval Construction Battalion in the South Pacific.

V. F. Headapohl (A'33) formerly engineer, American Telephone and Telegraph Company, New York, N. Y., has been commissioned lieutenant in the United States Naval Reserve.

OBITUARY

John Stone Stone (A '08) inventor and consulting engineer, died May 20, 1943. Born September 26, 1869, at Dover, Va., he studied at the Columbia University School of Mines and at Johns Hopkins University. From 1890 to 1899 he was employed as an experimentalist in the laboratory of the American Bell Telephone Company, Boston, Mass. He continued with that company in the position of general consulting engineer until 1920. During this period he was a special lecturer on electric oscillations and their applications at the Massachusetts Institute of Technology, Cambridge, for six years. He was vice-president and chief engineer of the Stone Telephone and Telegraph Company, Boston, from 1902 to 1908 when he became president. From 1920 to 1935 he was associate engineer at large in the department of development and research, American Telephone and Telegraph Company, San Diego, Calif. The holder of numerous American and foreign patents pertaining to telephony and wireless telegraphy, he frequently contributed to scientific publications. The Edward Longstreth Medal was awarded him for his paper, "The Practical Aspects of the Propagation of High-Frequency Waves Along Wires," by the Franklin Institute in 1913, and the medal of honor of the Institute of Radio Engineers for distinguished service in radio communication in 1923. A fellow of the Institute of Radio Engineers, he served as president during 1914–15. He was also a fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science, and a member of the Society of Wireless Telegraph Engineers and the Franklin Institute.

Ernest W. Muller (A '05, M '13) consulting engineer, Kaiser, Muller and Davies, New York, N. Y., died April 8, 1943. He was born in Rome, Ga., March 5, 1875. His first electrical work was wiring installations at which he was engaged from 1892 to 1894. From 1894 to 1897 he did similar work for the contracting firm of Hatzel and Buehler, New York, N. Y. In 1897 he joined the firm of Mailloux and Knox, Consulting Engineers, New York, N. Y., for whom he became designing and supervising engineer. As such, he was active in the electrification of many of the public buildings, stores, hospitals, and educational institutions in New York and near-by

cities. From 1919 to 1943 he was a member of the firm of Kaiser, Muller and Davies. There he specialized in the designing and development of feeder and cable distributing systems and power plant installations. In recent months he had worked with the War Production Board in its efforts to conserve copper and other vital war materials used in electrical installations. He was a member of the New York Association of Consulting Engineers, the Society of American Military Engineers, and a past vice-president of the New York Electrical Society.

William Edwin Douglass (M '37) manager, Panhandle division, Monongahela West Penn Public Service Company, Wellsburg, W. Va., died November 11, 1942. Born April 29, 1890, at Elmwood, Ill., he received the bachelor of science degree from Knox College in 1913 and the degree of electrical engineer from the University of Arkansas in 1919. In 1913 he entered the apprentice course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. From 1914 to 1919 he was engaged in transformer design and in 1919 was transferred to the company's central station section. In 1923 he entered the employ of the Wisconsin Valley Electric Company, Wausau, where he was charged with generation, and transmission and distribution. He joined the Monongahela West Penn Company as manager of its Clarksburg (W. Va.) division in 1925. In 1932 he was made manager of the Panhandle division. He was a member of the Iron and Steel Association, the American Ceramic Engineering Society, and an ex-chairman of the American Red Cross flood disaster committee.

Albert H. Kreul (A '19, M '32) assistant superintendent, electrical maintenance and construction, Portland (Oreg.) General Electric Company, died May 5, 1943. Born June 14, 1884, at Fennimore, Wis., he was graduated from Iowa State College with the degree of bachelor of science in electrical engineering in 1908 and from the Northwestern College of Law in 1918. His death terminated a 33-year association with the General Electric Company which he joined in 1910. Until 1920 he worked in the meter and service department. From 1920 to 1931 he was engineer in the electrical maintenance and installation department. In 1931 he was made assistant superintendent of the electrical maintenance and construction department. Active in Institute affairs, he served as chairman of the Portland Section for 1930–31 and as a member of the Pacific Coast Convention committee in 1938.

Joseph A. Robinson (A '30) sales engineer, National Carbon Company, New York, N. Y., died May 16, 1943. He was born November 26, 1883, at Waupun, Wis. From 1905 to 1907 he was engaged in research on primary batteries. In 1908 he entered the sales department of the Northwestern Storage Battery Company, Milwaukee, Wis. Since 1911 he had been with the National Carbon Company, first in Cleveland, Ohio, and from 1930 to 1936 in the company's Chicago, Ill., office. He returned to the Cleveland office in 1937 and in 1941 was transferred to New York.

Peter Clark Gill (A '24, M '32) superintendent of transmission and distribution, British Columbia Electric Railway Company, Vancouver, died April 25, 1943. He was born February 22, 1888 at Prescott, Ont., and received his bachelor of science degree in electrical engineering from McGill University in 1910. He immediately entered the distribution engineering department of the British Columbia Electric Railway Company and, in 1914, was given charge of maintenance and construction of the distribution system. In 1929 he was made superintendent of distribution and transmission.

Dudley Owen Nash (A '31, M '38) engineer, sales promotion department, General Cable Corporation, New York, N. Y., died November 6, 1942. He was born September 10, 1899, in Poolville, N. Y. During his service in the United States Army from 1917 to 1919 he worked with antiaircraft searchlights. He entered the employ of the Municipal Light and Power Company, Sherburne, N. Y., in 1919 and engaged in central station operation and construction and maintenance work until 1921. From 1922 to 1929 he managed his own contracting and electrical equipment firm. He joined the General Cable Corporation first in 1929 as specialist and sales engineer. After a short time, from 1934 to 1936, with the Bryant Electric Company, Bridgeport, Conn., as assistant consulting engineer, he returned to the General Cable Corporation.

Robert Henry Anthony (A '17) sales engineer, Boston, Mass., died May 1, 1943. He was born November 17, 1877, at East Providence, R. I., and began his engineering career with the New York, New Haven and Hartford Railroad where he was employed from 1895 to 1911 as roadmaster's chief clerk, engineer, and track supervisor. From 1911 to 1915 he worked as salesman for James C. Barr Company, Boston, Mass. In 1915 he joined R. Thomas and Sons as New England sales representative, and in 1921 he became New England sales manager for the company. Since 1935 he had operated in Boston his own firm which acted as manufacturers representative for numerous companies including the Electroline Company, the G. and W. Electric Speciality Company, the Memco Engineering and Manufacturing Company, the Merit Glove Company, the Minerallac Electric Company, the Naugle Pole and Tie Company, the Pennsylvania Transformer Company, Schweitzer and Conrad, Inc., and the R. Thomas and Sons Company.

David Douglas Murphree (A '40) distribution engineer, Southwestern Gas and Electric Company, Shreveport, La., died May 4, 1943. He was born at Thomaston, Tex., November 14, 1899, and received the bachelor of science degree from the Texas Agricultural and Mechanical College in 1921. From 1927 to 1929 he was distribution engineer with the Galveston (Tex.) Electric Company. He held the same position with the Central Power and Light Company, San Antonio, Tex., from 1929 to 1932. In 1933 he was employed in the commercial department of the San Antonio (Tex.) Public Service Company and in 1936 became distribution engineer with the Southwestern Gas and Electric Company.

Ralph Harold Chadwick (A '17, M '26) assistant to the manager in charge of engineering, General Electric Company, Fort Wayne, Ind., died May 29, 1943. Born at Gardiner, Maine, February 6, 1892, he was graduated from Brown University with the degree of bachelor of science in electrical engineering in 1912. He was enrolled in the General Electric Company test course at Fort Wayne for six months and entered the transformer engineering department in January 1913. In 1926 he was made engineer of the transformer department and in 1941 he was appointed assistant to the manager in charge of engineering. He had served as president of the Fort Wayne engineers club.

Jeth Wesley Dodson (A'38) major, Signal Corps, United States Army, died May 12, 1943. Born in Bryan County, Okla., May 15, 1909, he received the degree of bachelor of science in engineering from the Texas Agricultural and Mechanical College in 1936. From 1936 to 1942 he worked as meterman for the Oklahoma Gas and Electric Company, Ada. He entered the Army in 1942 as a first lieutenant.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on June 17, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Attwood, S. S., prof. of elec. engg., Univ. of Michigan, Ann Arbor, Mich.
Bailey, E. L., elec. engr., Chrysler Corp., Detroit, Mich.
Camilli, G., research & development engr., General Elec. Co., Pittsfield, Mass.
Hartley, P. H., chief engr., Philadelphia Elec. Co., Philadelphia, Pa.
Ross, R. H., division plant supt., American Tel. & Tel. Co., Philadelphia, Pa.
Seelye, H. F., senior engr., Detroit Edison Co., Detroit, Mich.

To Grade of Member

Adams, J. A., senior engr., Philadelphia Elec. Co., Philadelphia, Pa.
Angevine, O. L., engr., Stromberg-Carlson Co., Rochester, N. Y.
Bedford, B. D., elec. engr., General Elec. Co., Schenectady, N. Y.
Beeman, D. L., engr., General Elec. Co., Schenectady, N. Y.
Bond, E., elec. engr., Union Carbide Co., Niagara Falls, N. Y.

Broschart, C. B., application engr., Bradley Co., Philadelphia, Pa.
Brown, F. F., plant engr., Indiana Bell Tel. Co., Indianapolis, Ind.
Caldwell, B. H., designing engr., General Elec. Co., Schenectady, N. Y.
Charlesworth, G., elec. engr., Iowa State Commerce Commission, Des Moines, Iowa.
Dunnewold, L. J., toll plant engr., Indiana Bell Tel. Co., Indianapolis, Ind.
Ericson, R. C., engr., Northern Indiana Pub. Serv. Co., Hammond, Ind.
Falck, K. J. G., senior engr., Philadelphia Elec. Co., Philadelphia, Pa.
Fehr, R. O., engr., General Elec. Co., Schenectady, N. Y.
Frey, H. A., research and development engr., Locke Insulator Corp., Baltimore, Md.
Halberg, M. N., member of Industrial Engg. Dept., General Elec. Co., Schenectady, N. Y.
Johnson, T. C., elec. engr., General Elec. Co., Schenectady, N. Y.
Jones, B. W., consulting engr., General Elec. Co., Schenectady, N. Y.
Kennedy, A., engr., General Elec. Co., Schenectady, N. Y.
Kuehni, H. P., elec. engr., General Elec. Co., Schenectady, N. Y.
Lauder, A. H., elec. engr., General Elec. Co., Schenectady, N. Y.
LeVesconte L. B., district engr., Westinghouse E. & M. Co., Chicago, Ill.
Levers, L. G., elec. engr., General Elec. Co., Schenectady, N. Y.
Lockie, A. M., development engr., Westinghouse E. & M. Co., Sharon, Pa.
Merrick, E. G., elec. engr., General Elec. Co., Schenectady, N. Y.
Pendleton, W. W., research engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Peters, R. H., district engr., Southwestern Bell Tel. Co., Houston, Texas.
Pope, R., member of technical staff, Bell Tel. Labs., Inc., New York.
Robinson, P. V., section head, General Elec. Co., Schenectady, N. Y.
Schroeder, E. H., div. supt. of installation, Western Elec. Co., Philadelphia, Pa.
Stack, G. E., control engr., General Elec. Co., Schenectady, N. Y.
Sweet, A. L., section head, General Elec. Co., Schenectady, N. Y.
Walker, W. G., senior engr., Philadelphia Elec. Co., Philadelphia, Pa.
Ward, S., draftsman and supervisor, Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Westendorp, W. F., research engr., General Elec. Co., Schenectady, N. Y.
Wetmore, W. F., elec. engr., Detroit Edison Co., Detroit, Mich.
Wilson, A., mgr., transmision and distribution dept., Philadelphia Elec. Co., Philadelphia, Pa.

36 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1943, or September 30, 1943, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Becker, J. A., Bell Tel. Co., New York, N. Y.
Sheldon, H. H., 80 West 40th St., New York, N. Y.

To Grade of Member

Ahmed, A. A. (Re-election), Ein-Shems, Nr. Cairo, Egypt.
Bjorquist, C. H., Bonneville Pr. Adm., Portland, Oreg.
Bowman, E. K., Gen. Elec. Co., Schenectady, N. Y.
Braunwarth, W. W. (Re-election), Amer. Tel. & Tel. Co., Phila., Pa.
Brooke, G. M. (Re-election), U. S. Maritime Comm., Oakland, Cal.
Desilvers, J. R., Quebec Pub. Serv. Board, Montreal, Canada.
George, B. J. (Re-election), Kansas Pr. & Lt. Co., Kansas City, Mo.
Hieronymus, T. G. (Re-election), Kansas City Pr. & Lt. Co., Kansas City, Mo.
Mintz, N. M., N. M. Mintz & Associates, Chicago, Ill.
Parrish, E. W., Florida Pr. Corp., St. Petersburg, Fla.
Pearce, W. J., Mutual Boiler Ins. Co., Boston, Mass.
Quinn, R. F., Gen. Elec. Co., Schenectady, N. Y.
Rollo, W. S., British Army Staff, Washington, D. C.
Sheffield, H. M., Douglas Aircraft Co., Long Beach, Cal.
Swank, A. J. (Re-election), Pacific G. & E. Co., San Francisco, Cal.

15 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Anderson, A. F., Boston Edison Co., Boston, Mass.
Anderson, H. C., Jr., Gen. Elec. Co., Schenectady, N. Y.
Berry, T. M. (Re-election), Gen. Elec. Co., Schenectady, N. Y.
Bloomquist, W. C., Gen. Elec. Co., Schenectady, N. Y.
Broch, F. J., Stone and Webster, Boston, Mass.
Hamilton, L. L., Gen. Elec. Co., Boston, Mass.
Swarthout, R. W., Gen. Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Bennon, M., Philadelphia Navy Yard, Philadelphia, Pa.
Bowen, C. M., Consolidated Gas El. Lt. & Pr. Co., Baltimore, Md.
Brewer, N. R., Arthur G. McKee Co., Cleveland, Ohio.
Douglas, A., Cleveland Elec. Ill. Co., Cleveland, Ohio.
Ellerbe, E. B. (Re-election), W. E. & M. Co., Charleston, W. Va.
Eppley, I. C., Dayton Pr. & Lt. Co., Dayton 2, Ohio.
Fox, J. L., W. E. & Mfg. Co., Erie, Pa.
Gallagher, E. I., Phila. Elec. Co., Philadelphia, Pa.
Gibbs, J. C., Cons. G. E. & Pr. Co., Baltimore, Md.
Harding, R. L., Susquehanna Elec. Co., Conowingo, Md.
Klotz, J. W., Phila. Navy Yard, Phila., Pa.
Kyser, R. H., Naval Research Lab., Washington, D. C.
McCleery, H. D., Fairbanks Morse & Co., Cleveland, Ohio.
Miller, W. S., I-T-E Circuit Breaker Co., Phila., Pa.
Monroe, W. L., W. E. & M. Co., Sharon, Pa.
Picking, J. W., Reliance Elec. & Engg. Co., Cleveland, O.
Plummer, C. B., Federal Communications Com., Washington, D. C.
Spikes, C. W., Sr., Steel Improvement & Forge Co., Cleveland, O.
Stritehoff, D. A., Cons. G. E. & Pr. Co., Baltimore, Md.
Walch, K. R., Gen. Elec. Co., Philadelphia, Pa.
Yanda, G. J., Cleveland Elec. Ill. Co., Cleveland, Ohio.

3. New York City

Barnard, K. H., Pacific Mills, New York, N. Y.
Brechbuhl, L. M., Fed. Tel. & Radio Corp., Newark, N. J.
Broughton, L. I. (Re-election), Bell Tel. Co., New York, N. Y.
Feinsilver, A. S., Crocker-Wheeler Mfg. Co., Ampere, N. J.
Goddard, R. C., Nat. Union Radio Corp., Newark, N. J.
Harris, R. W., Kerite Cable Co., New York, N. Y.
Johnson, H., Sperry Gyroscope Co., Inc., New York, N. Y.
Jordan, W., III, Newark College of Engg., Newark, N. J.
Lang, H. S., Curtis Wright Corp., Caldwell, N. J.
Lewson, M., Camp Evans Signal Lab., Belmar, N. J.
Piaszak, A. M., U. S. Navy, New York, N. Y.
Sattler, R. T., 150 Pacific Ave., Jersey City, N. J.
Wang, P. Y., Nat. Resources Comm. of China, New York, N. Y.
Wilentz, E. S., Cox & Stevens, New York, N. Y.

4. Southern

Haley, J. L., Jr., Memphis L. G. & W. Div., Memphis, Tenn.
Mallory, F. D., Jr. (Re-election), Florida Lt. & Pr. Co., Sarasota, Fla.

5. Great Lakes

Ax, L. S., Tri-State College, Angola, Ind.
Ewy, A., Allis Chalmers Mfg. Co., West Allis, Wis.
Gay, M. F., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Green, F. A., W. E. & M. Co., Indianapolis, Ind.
Kemp, H. L., Pub. Ltg. Commission, Detroit, Mich.
Link, E. A., Line Material Co., So. Milwaukee, Wis.
Rockhill, A. H., Bendix Prod. Corp., South Bend, Ind.
Scott, N., General Motors Co., Detroit, Mich.
Strelzoff, J. A., Michigan State College, E. Lansing, Mich.

6. North Central

Bowen, L. R., Pub. Serv. Co. of Colorado, Denver, Col.
Burgess, M. L., W. E. & M. Co., Omaha, Nebraska.

7. South West

Mark, P. W., Kansas G. & E. Co., Wichita, Kans.
McCarthy, W. G., Jr., Kansas City Pr. & Lt. Co., Kansas City, Mo.
Turrell, H. M., Kansas City Pr. & Lt. Co., Kansas City, Mo.
Wentz, R. L., Kansas Gas & Elec. Co., Wichita, Kansas.

8. Pacific

Brand, S., Douglas Aircraft Co., Santa Monica, Cal.
Burch, R. O., Butcher Elec. Co., San Jose, Cal.
Garman, L. G., Mare Island Navy Yard, San Francisco, Cal.
Johnston, J. T., Gen. Elec. Co., Los Angeles, Cal.
Jung, H. E., Southern Cal. Edison Co., Los Angeles, Cal.
Kirsch, W. R., Bethlehem Steel Co., San Francisco, Cal.
Koehne, K. H., Mare Island Navy Yard, San Francisco, Cal.
Moore, E. J., Cons. Vultee Aircraft Corp., San Diego, Cal.
Perrin, W. G., Glendale Pub. Serv. Dept., Glendale, Cal.
Price, W. J., Moore Dry Dock Co., Oakland, Cal.
Reinhard, J. W., Bur. of Pr. & Lt., Los Angeles, Cal.
Thompson, O. G., Gen. Elec. Supply Corp., San Diego, Cal.

9. North West

Allen, J. W., Boeing Aircraft Co., Seattle, Wash.
Barnes, F. P. (Re-election) Gen. Elec. Co., Seattle, Wash.
Gilbert, R. M., W. E. & M. Co., Seattle, Wash.
Gue, W. M., W. E. & M. Co., Seattle, Wash.
Lantz, M. J., Bonneville Pr. Administration, Portland, Oreg.
Jordan, W. G., Jr., Gen. Elec. Co., Seattle, Wash.
Murphy, H. A. (Re-election), Montana Pr. Co., Philipsburg, Mont.
Parker, F. D. (Re-election), Bonneville Pr. Adm., Vancouver, Wash.
Pattison, J. R., A. S. Schulman Elec. Co., Provo, Utah.
Renz, R. E., W. E. & M. Co., Butte, Mont.

10. Canada

File, S. E., Powerlite Devices, Ltd., Montreal, Quebec, Canada.
Jorgensen, R., Shawinigan Water & Power Co., Montreal, Quebec, Can.
Kelsey, E. S., Northern Elec. Co., Montreal, Quebec, Canada.
Mitchell, D., Toronto Shipbldg. Co., New Brunswick, Canada.
Sutton, A. J., Montreal Lt. Heat & Power Cons., Montreal, Quebec, Can.

Elsewhere

Anscome, L. D., British Thomson Houston Co., Rugby, England.
Ball, C. E., H. M. Naval Base, Portland, Dorset, England.
Clipperton, J. E., Trinidad Leaseholds Ltd., Trinidad, B. W. I.
Hendry, N., Rotax Ltd., London, England.
Higgs, V. A., Ministry of Aircraft Prod., London, England.
Johnston, B. H., North Canterbury Hospital Board, Christchurch, N. Z.
Moguel, H. E., Mexican Light & Power Co., Mexico, D. F.
Velez, J. F., Fed. Communications Comm., San Juan, Puerto Rico.

Total to grade of Associate
United States and Canada, 86
Elsewhere, 8

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York 18, N. Y.

Aloe, Abbas H., 294 S. Wilson Ave., Pasadena, Calif.
Baisley, R. C., 2535 Van Vranken Ave., Schenectady, N. Y.
Bartelink, E. H. B., 1386 Keyes Ave., Schenectady, N. Y.
Bershad, Laurence P., 320 E. Chester St., Long Beach, L. I., N. Y.
Bolljahn, John T., 1436 T St., S. E., Washington, D. C.
Bourque, Hugh O., 1396 Peachtree St., Atlanta, Ga.
Campbell, Dudley E., 834 E. Olive St., Los Angeles, Calif.
Cross, Charlie, 6544—18th Ave., N. E., Seattle, Wash.
Greene, Ensign Daniel E., Jr., 17 School St., Hanover, N. H.
Heckel, Richard D., 426 S. Sycamore St., Wilmington, Del.
Howell, Walter D., Naval Training School, Dartmouth College, Hanover, N. H.
Johnson, James Steven, 1002—8th St., Lake Charles, La.
Jump, James E., 1004 Union St., Schenectady, N. Y.
Lowy, Walter Marion, 6509 Cleveland Ave., Baltimore, Md.
Mushrush, Roy S., Jr., 335 South St., Pittsfield, Mass.
Nelms, William L., Jr., Box 723, Orangeburg, S. C.
Ortner, Max, Jr., 1831 N. Dayton St., Chicago, Ill.
Pecha, Anton F., 22-66—35th St., Astoria, L. I., N. Y.
Pinckert, Walter F., 203 Elmhurst St., San Antonio, Texas.
Sherman, Leslie S., 1186 Wendell Ave., Schenectady, N. Y.
Sulzer, John Henry, Columbia Ave., Union Beach, N. J.
Waychus, Felix John, Austin Hall, Harvard University, Cambridge, Mass.
Webster, J. D., Jr., Temperance Hall, R.D. 2 Schenectady, N. Y.

23 Addresses Wanted

OF CURRENT INTEREST

Inter-American Commission Plans Postwar Development

The United States and the republics of Latin America will continue to co-operate with private enterprise, through an inter-American commission, to further the economic development of the Western Hemisphere, William F. Machold, executive director of the United States Commission of Inter-American Development, stated in a recent issue of *Foreign Commerce Weekly*.

As a result of the Panama Conference of 1939, the governments in each of the 21 Latin-American republics took action in forming and recognizing a system of national commissions, each comprised of five to seven members. With the formation in 1943 of the United States Commission for Inter-American Development, under the chairmanship of Eric A. Johnston, the chain of national commissions was completed. Co-ordinating council for the system is the Inter-American Development Commission, of which Nelson A. Rockefeller is chairman.

Brief though the span of the system's existence is, it has already put into effect those of its aims which need not be postponed for the duration of the war, declared Mr. Machold. Such objectives are: advisory assistance to private enterprise, particularly on a mixed United States and Latin-American capital basis; field studies, such as the United States vegetable oil mission to Brazil, the survey of Caribbean fisheries, and the study of Peruvian manual industries; provision of technical assistance, such as the delegation of mining engineers to Brazil and Peru, and of industrial engineers to Mexico, and the creation of a technical division within the Washington, D. C., office of the parent commission; and the preparation and dissemination of studies interpreting wartime United States government and business activities affecting the Latin-American trade and industry.

Long before Pearl Harbor, however, and before the formal organization of our own commission, the United States contributed to the Good Neighbor policy through stabilization loans, export–import bank credits for needed capital goods which were delivered, and the carrying out of a program to purchase from the Latin-American republics commodities we had formerly bought elsewhere, as well as the increased amount of raw materials needed for our expanding defense effort. Since Pearl Harbor, our government has concentrated on developing maximum production of vital war materials, including copper, tin, tungsten, rubber, quinine, and fibers. Closely allied with these activities are health and sanitation, food production, development of highway, railroad, and air transportation, and rehabilitation operations.

The contributions of our allies in the Western Hemisphere already are a substantial weight in the scales of world struggle, and as members of the United Nations they will share in the conversion of war production to peacetime uses and outlets. The war has not wholly precluded the development or expansion of consumer-goods production and light industries such as textile mills, cement plants, and rolling mills. Construction of the widely known Brazilian steel mill continues. But for the most part, Latin-American development projects must be deferred for the duration, since the exigencies of war point to less shipping space and less machinery and materials.

In the postwar period, the participation of private enterprise in the United States as a partner in hemispheric industrial expansion will be of material assistance in meeting local capital and technological needs. We have the capital, technical skill, and managerial knowledge. Latin America has natural resources and manpower. A mingling of these elements will further the economic development of the other Americas and will increase their per capita purchasing power and capacity to absorb goods. Among many subjects, knowledge must be obtained concerning laws and taxes, the nature and demands of markets, availability of labor, raw materials, and transportation, climatic conditions, and business customs. Then, with the cessation of hostilities, the Americas can widen their scope of activities and undertake the long-range objectives for which sound preparation is being made now.

Army–Navy Use of Radar Described by OWI

The silence which has hitherto surrounded radar, the United Nations' secret weapon that has been employed so effectively in World War II, has been partially lifted at last by an Army–Navy release through the Office of War Information.

A radio detection and ranging device which utilizes the reflecting characteristic of radio waves to determine the direction, distance, and elevation of an enemy object, radar equipment provides the data necessary to aim a gun accurately on a distant enemy airplane or ship beyond the visibility range of the most powerful telescope. It is used by static ground defenses to direct antiaircraft fire on hostile airplanes through a cloud cover and is installed on airplanes and warships as a means of locating and intercepting the enemy in the dark.

Two fundamental discoveries opened the electronic spectrum to radar equipment. On the basis of electronic theory, it was demonstrable that radio waves are reflected as well as absorbed or filtered through solid substances. However, until a few years ago, no one had succeeded in detecting the reflected impulses. Recent research has led to the development of receiving instruments which can pick up and record these waves.

A second discovery has been the creation of instruments which count time intervals smaller than a split thousandth of a second. Although work in this direction has been going forward for years, it was recent experiment that resulted in such high precision as to open the way to radar.

Its advantage over the telescopes and acoustic detectors previously used is one of speed. Sound, picked up by an acoustic detector, travels at approximately 700 miles an hour, or only about twice the speed of a fast bomber. But radio waves, which operate over a much greater distance, carry the warning of approaching airplanes with the speed of light—186,000 miles per second.

As a result of experiment by prominent British and American scientists in the ultra-high-frequency field, radar equipment was devised in both countries in the middle '30's. The British, who call their system the radiolocator, made the first practical use of radar when they withstood the Nazi bombers in the summer of 1940. The American development was done by Army Signal Corps, Navy, and civilian laboratories. American production placed proved field radar apparatus in the hands of the armed forces several months before the Japanese attack on Pearl Harbor, and it was these instruments which detected and located approaching airplanes some 30 minutes before the attack was launched.

Scientifically, radar has the same genealogy as the familiar radio. The British physicist, William Clerk Maxwell, in 1864, demonstrated mathematically that light and electricity move in the same medium, and that electricity and light share many of the same characteristics. In 1887, Heinrich Hertz succeeded in producing electromagnetic waves which, as Maxwell had predicted, could be detected at some distance from the originating spark. In the 1890's, Guglielmo Marconi was experimenting with equipment designed to send out longer stronger waves, on the one hand, and on the other hand, to pick up waves at greater distances. He used an aerial and ground on both his sending and receiving apparatus.

The next important step was the use of pioneer vacuum tubes in 1906 by Doctor Lee DeForest. In 1915, Doctor Irving Langmuir designed a tube similar to those used today. The microphone, which translates our speech into radio waves, and the receiver which translates these waves into the radio programs to which we listen, while vital to the development of radio, are not essential to radar.

TVA Completes 13 Dams in Ten-Year Existence

After ten years of operation the Tennessee Valley Authority can point to an achievement record showing 13 large dams constructed, 385 miles of nine-foot navigable channel cleared for year-round transportation, nearly 30,000,000 kilowatt-hours of electric energy generated, 150,000,000 seedling trees planted, and 500,000 tons of phosphate and fertilizer processed, according to a recent review published in *Engineering News Record*.

Eight of the 13 dams into which have gone 7,600,000 cubic yards of concrete and 20,000,000 cubic yards of earth and rock have been constructed under wartime stringencies since 1940. The installed power capacity of its projects has increased from 1,000,000 kw to 1,500,000 kw since Pearl Harbor was attacked. TVA plants have also felt the war stimulus. They are among the largest producers of phosphorous products for incendiary bombs, smoke screens, and tracer bullets. Ammonia and ammonium nitrate for munitions and calcium carbide for synthetic rubber are manufactured by the plants.

About 75 per cent of the installed power capacity of the hydroelectric and steam plants built and purchased by the TVA is contributing to war production. These plants have a power capacity of 1,635,640 kw to which installations now in progress will add 453,200 kw. Nearly 6,000 miles of transmission lines are now in service. Thus the TVA system now ranks second among the power systems of the United States.

Other permanent improvements have resulted from TVA activity in checking soil erosion and in aiding the agricultural economy of the region by developing many small machines for food and feed processing designed primarily for the small, low-income farm unit predominant in the region. Pilot plants for extracting native kaolins for chinaware, alumina from clay, and magnesium from olivene rock have been set up.

On the Tennessee and its tributary rivers, flood storage of 8,000,000 acre-feet in the reservoirs has helped reduce flood crests in the Tennessee, Ohio, and lower Mississippi rivers. Navigation has increased from 32,660,000 ton-miles in 1933 to 161,470,000 ton-miles in 1942 as TVA control kept a more uniform supply of water in the river bottoms.

For the future TVA has scheduled the completion of the Fort Loudon and Kentucky dams and dredging operations required to extend the 9-foot navigation channel from the mouth of the Tennessee river to Knoxville, Tenn. River freight terminals are also under construction.

The impact of the program on the four states in the valley, Tennessee, Alabama, Georgia, and Mississippi, may be indicated by figures recently released by TVA Director J. P. Pope. According to these estimates economic progress in the area for the past decade has exceeded the average for the country. Manufacturing plants in the four states increased production 52 per cent from 1933 to 1939 compared with 32 per cent for the nation. Wage earnings increased 40 per cent compared with 36 per cent elsewhere. Per capita income rose 75 per cent compared with 56 per cent for the whole country.

Shortage of Engineers Threatens War Industry

Between 40,000 and 50,000 engineers are vitally needed in war industry to raise production to capacity or to start new productive units operating before the end of 1943, according to a report made to Paul V. McNutt, chairman of the War Manpower Commission, by the National Roster of Scientific and Specialized Personnel.

With the graduating classes of the country's engineering schools supplying only about 17,000 new engineers, of whom 6,000 are committed to the armed services, there must be a reapportioning of those already employed. The report points out that the plants which have reached the stage of routine production are in a better position to stand the loss of technically trained men than the expanding war industries.

In appraising the numbers that might be made available for war production in this manner, the report estimates that, of 280,000 American engineers, 19 per cent are in the armed forces or in civilian jobs in the War and Navy Departments; 12 per cent are in other governmental positions; 49 per cent are employed in manufacturing, mining, and construction; and 20 per cent are employed in transportation, communication, public utilities, private consulting offices, and educational institutions. The fields of electrical, radio, mechanical, aeronautical, marine, and industrial engineering are those in which the scarcity is most apparent.

In addition the report suggests that the 1943 engineering graduates who are not needed by the armed forces to fill specific technical posts may be of greater aid in the war effort if they are released to war industry.

Some relief for the situation may be expected from the more profitable employment of nonengineering personnel. Skilled workers must be occupied at their highest skills, while less technical operations can be left to men and women with more limited training. The simpler engineering tasks may be turned over to technical assistants. The engineering, science, and management war training college courses sponsored by the government and now open to high school graduates will provide such assistants.

Marine Diesels Put Under Working Strains

This General Electric water-cooled inductor dynamometer is pictured as it is employed at the Enterprise Engine and Foundry Company, San Francisco, Calif., in giving a ten-day test under simulated operating conditions to a 1,000-horsepower eight-cylinder Diesel engine used in many types of seacraft. The dynamometer can absorb 3,500 horsepower over a range of 850 to 2,500 rpm.

Electronic Checkup Given to Army's Powder

The modern United States Army not only keeps its powder dry but examines powder production runs for variations in ballistic factors that might cause errors in fire-control calculations. This makes possible greater precision in setting up intricate ballistic formulas.

The powder is tested by exploding a sample in a strong sealed container. Electric voltages from the confined detonation reach the horizontal and vertical plate pairs of a cathode-ray tube through suitable amplifiers. The resulting oscillogram is photographically recorded and later analyzed. The screen calibrates the qualitative story of the graph by applying a series of dots arranged in a matrix. Each luminous dot is electronically placed on the screen so that the horizontal or vertical distance between any two adjacent dots is a constant known factor.

The operator of the oscillograph actuates a plunger which automatically opens the camera shutter, turns on the cathode-ray beam, fires the powder charge, switches the input of the deflection amplifiers from bomb chamber to matrix generator, causes the "equipotential" matrix to appear, turns off the electron beam, and then closes the camera shutter. The machine used to perform this series of operations was designed and built by the Allen B. Dumont Laboratories, Inc., Passaic, N. J.

Sea-Rescue Lamp Designed for Life Rafts

A midget searchlight built into a bulb no larger than a walnut has been developed by the lamp division of Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., to aid the rescue of aviators forced down at sea.

Designed at the request of the United States Navy, the lamps will be packed with the rubber life rafts with which all ocean-flying military aircraft are now equipped. Each man of a plane crew forced down at sea will wear one of them fitted on a band around the head, like a miner's cap, so that both hands can be free to hold on in rough weather.

One half of the six-watt bulb is silvered to provide its own reflector and to prevent diffusion of the beam. The lamps will be wired to a small hand-cranked generator which is included in the raft equipment to supply power for the radio. They can also be flashed as signal lamps by means of a "trigger switch."

Theoretically, the tiny incandescent unit will project a 1,500-candlepower beam visible for 60 nautical miles, but in practice, water vapor in the air reduces the visibility range of the beam somewhat. If burned all night long, it is estimated that one of the lamps would last about ten nights or 100 hours.

Bituminous Coal Users Urged to Order Now

A government program to spread the mining and delivery of bituminous coal more uniformly over the summer and thus prevent a heavy seasonal strain on production and transportation next winter has been announced by Solid Fuels Administrator Harold L. Ickes.

Stating that the adequacy of next winter's coal supply depends on the success of the program, Mr. Ickes placed responsibility for this success with the consumer whose orders must set it in motion.

"A bituminous coal user's best wartime fuel insurance is to place his order now; allow his dealer or supplier the greatest possible latitude as to kind, quality, and size; co-operate with his dealer on delivery arrangements, and store the coal as it can be made available," according to Mr. Ickes.

He urged consumers to accept any usable coal their dealers recommend rather than risk being left without fuel. In stressing the importance of ordering the coal now, he said that "in view of the uncertainties about conditions which might arise next winter in the regions where bituminous coal is now being produced, we cannot afford to lose the production and distribution of a single ton that can be moved this summer."

A program to insure an adequate supply of anthracite coal is also being formulated according to the administrator.

WPB Reports Progress of Copper Recovery

Some 197,000,000 pounds of idle and excessive copper scrap has so far been turned into war-production channels, according to a recent announcement of the War Production Board. Of this amount, 62,000,000 pounds is in the form of fabricated copper and copper-base alloy. The regular scrap market has absorbed 30,000,000 pounds while 93,000,000 pounds has been allocated for remelting. Users were found for 56,000,000 pounds in the form in which it was reported. The remaining 17,000,000 pounds has been retained by owners for production.

The foregoing amounts represent two thirds of the amount of copper scrap reported to the WPB in response to its efforts to locate the 400,000,000 to 500,000,000 pounds of scrap which experts estimated to be extant. So far 114,000 firms have been approached and plans are under way to reach 98,000 plumbers, building contractors, and their suppliers.

Of the remaining 100,000 pounds reported, approximately 36,000,000 pounds consists of assembled products contaminated with materials not suitable for copper scrap. Arrangements for removal of the remainder by the Copper Recovery Corporation are still in progress.

Brazilians in United States Study Powder Metallurgy

New applications of the science of powder metallurgy as used in the United States to speed war production will be carried back to Brazil by two scientists now studying here. They are Doctor Tharcisio D. deSouza Santos and Vincente Chiaverini, engineers from the Institute of Technological Research in Sao Paulo, now investigating metallurgical processes in the metal-powder laboratory of Stevens Institute of Technology, Hoboken, N. J.

After an intensive three-month course and a month spent in visiting American plants and factories, they will return to Brazil to set up a metallurgical laboratory there. As yet, there is none in any educational institution in Brazil, they said. Doctor Santos plans to center his study on the operation of the high-frequency melting furnace, the production of carbide cutting tools, ore reduction, and the application of powder metallurgy. Mr. Chiaverini will specialize in hard metallic carbides and the operation of equipment used in their processing.

Latin Americans Study Rural Electrification in U. S.

Eighteen engineers from 14 Latin-American countries, who are in the United States studying rural electrification, recently completed a 3,900-mile tour of north, central, and eastern industrial centers. The trip enabled the men to observe the production of a full line of equipment for the construction and operation of rural power lines, generating plants, electrical labor-saving farm equipment, and other devices which will be needed for postwar rural electrification in their own countries.

The tour, arranged by the Rural Electrification Administration, in co-operation with the Office of Co-ordinator of Inter-American Affairs and the Office of Foreign Agricultural Relations in the Department of Agriculture, took the group to 15 industrial cities in eight states. Before their return home to start developing their own rural electrification programs they will visit REA-financed electric distribution systems under actual operating conditions.

This is the second year the REA has arranged for a delegation of Latin-American student-engineers to study the rural electrification program in this country.

Pacific Northwest Area Receives Power From Shasta Turbines

Two 75,000-kw turbine generating units, originally constructed for Shasta Dam of the Central Valley project in California, have been rushed into place at Grand Coulee Dam by the Bureau of Reclamation to meet additional load requirements in that area.

The Shasta units were completed in advance of the Shasta power plant, and the transfer was made in order to provide extra power for war industries in the Pacific Northwest. Other units will be available for Shasta by the time it is able to generate power. Because the turbines for the two projects were not of the same design, a number of adaptations were required in effecting the change.

The turbines operate at a capacity load of 103,000 horsepower at 330-foot head. It is expected that two more 108,000-kw generators also will be installed this year at Grand Coulee.

Brazil's Manufacture of Electric Motors Stimulated by War

The manufacture of polyphase electric motors in Brazil has made notable progress since the outbreak of the war, *Foreign Commerce Weekly* recently reported. Five com-

panies in Sao Paulo are now making motors of this type to take the place of those formerly supplied by Germany, Italy, and Belgium.

In 1940, the Sao Paulo plants produced 3,393 motors valued at about $101,000; in 1942, their output increased to 24,629 motors valued at approximately $923,100. This is said to be sufficient to meet most domestic requirements, except for large units.

So far as is known, single-phase motors are not now being manufactured in Brazil. It is reported, however, that at least one company is interested in entering that field.

Welding Library Established at Ohio State University

A new welding library, known as the A. F. Davis Welding Library, has been established at Ohio State University, according to E. N. Manchester, university librarian. It is the gift of A. F. Davis, vice-president and secretary, The Lincoln Electric Company, Cleveland, Ohio. Located in the Industrial Engineering Building, the library is under the supervision of J. R. Stitt, associate professor of engineering at the university. Though in its early stage of development, the collection already numbers over 700 volumes. A part of the library will be set aside for filing papers contributed by engineers representing original work in welding engineering.

Foreign Patent Applications Published. Annotated lists arranged by classes of patent applications formerly vested in enemy and enemy-occupied countries are being published in the weekly *Gazette* of the United States Patent Office. Part of the list of more than 3,000 applications will be published each week, according to the Office of the Alien Property Custodian in whom the patents are vested. However, a few applications of special military importance are being withheld from publication. For a more detailed account of the patent applications and the patents which have been vested from the enemy see *Electrical Engineering*, June 1943, page 277.

1,400 Kw for Electronic Tin Fusing

Electron-tube oscillators supply energy at 200,000 cycles per second to the induction heating coils that flow electrolytically deposited tin plate on steel strip into a smooth shiny surface. Shown here are seven oscillator tank circuits for 200-kw units being assembled at the radio division of the Westinghouse Electric and Manufacturing Company, Baltimore, Md.

OTHER SOCIETIES •

Industrial Research Institute Holds Annual Meeting

A comparison of present and probable future research organization in Great Britain and the United States was the topic of discussion at the general dinner session of the fifth annual meeting of the Industrial Research Institute held recently in New York, N. Y.

In bringing out the differences between the two countries, the proportionately larger amount of British government and trade association research activity because of the slower adoption of research by industry was emphasized by G. S. Whitby, formerly director, Chemical Research Laboratory, department of scientific and industrial research, Teddington, England. However, Doctor Whitby was hopeful that the present general recognition, in England, of the importance of postwar planning would lead to an increase in technical research. The preponderant place which American industrial research laboratories have taken in contributing to the increasing military superiority of the United Nations was pointed out by R. W. King (M '35) assistant vice-president, American Telephone and Telegraph Company, New York, N. Y. In his opinion, the impetus which the war has given to research may be accompanied by rising costs which will place such activity beyond the resources of private industry.

Sessions on new research tools, research management problems, co-operative intra-industry research, and the rating of research personnel were also attended by the 70 industrial executives and research directors who represented the 55 member companies of the Institute, during the two-day meeting.

New officers elected for the year 1943–44 were: *Chairman* of the executive committee, W. R. Hainsworth, vice-president, Servel, Inc., New York, N. Y.; *vice-chairman*, H. K. Work, manager of research and development division, general metallurgical department, Jones and Laughlin Steel Corporation, Pittsburgh, Pa. Committee members elected for three-year terms were: A. G. Ashcroft, product engineer, Alexander Smith and Sons Carpet Company, Yonkers, N. Y.; T. K. Cornwell, director of research, Sylvania Industrial Corporation, Fredericksburg, Va.; J. M. McIlvain, administrative supervisor, research and development, Atlantic Refining Company, Philadelphia, Pa.

ASA Compiles Standard on Electrical Symbols

Based on the principle of providing a fundamental symbol for each component part of an electric device, an, "American Standard Graphical Symbols for Power, Control, and Measurement," has been issued by the American Standard Association.

This standard is an attempt to obtain national acceptance of symbol and wiring-diagram standardization. From the funda-

mentals included in the standard, symbols for any complete electric device or unit of equipment can be prepared. The resulting standardized diagrams then can be understood readily and followed easily during wiring. Preference has been given to symbols which are simple in design and easy to understand and reproduce and are widespread in use and application. The drafting time required to draw them and the over-all appearance were both considered. Included in the standard are: elementary control wiring diagrams, controller wiring diagrams, external controller wiring diagrams, controller construction diagrams, and control sequence tables. As the ASA has presented them, the symbols are not all rigidly defined. It has been left to commercial usage to iron out differences of opinion about the best symbol in some instances. In such cases alternate symbols are given.

Future Meetings of Other Societies

American Chemical Society. September 6–10, 1943, Minneapolis, Minn.

American Institute of Mining and Metallurgical Engineers. Joint fuels conference, October 28–29, 1943, Pittsburgh, Pa.

American Society for Metals. Annual convention, October 18–22, 1943, Chicago, Ill.

American Society of Mechanical Engineers. Annual Meeting, November 29–December 3, 1943, New York, N. Y.

American Society for Testing Materials. Annual meeting, June 28–July 2, 1943, Pittsburgh, Pa.

National Safety Congress and Exposition, October 5–7, 1943, Chicago, Ill.

Copies of the standard may be procured from ASA headquarters, 29 West 39 Street, New York 18, N. Y.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Commutation in A-C Motors

To the Editor:

Some 40 years ago the theory of commutation was studied mathematically by Girault, Arnold and Mie, Pichelmayer, Rothert, Arnold, Rüdenberg, Ossanna, T. Reid, A. Press, and others, who set up fundamental differential equations and solved them either graphically or under certain simplifying assumptions for the d-c case, with a brush covering one segment or less.

In some cases, as in the article by Press in *Electrical World* December 16, 1905, the investigation was limited to the conditions existing at the last moment of short circuit in d-c machines which avoided the integration and yet gave a good picture of the phenomena. This analysis is feasible only if the brush covers one segment or less. No similar analysis for the a-c case seems to have been given. Such an analysis follows:

In reference to Figures 1 and 2, with armature at rest, the potential difference between segment 1 and brush b is

$$I_c[2(R+r)+w]+jI_c(\pm e_T \pm \omega L) \qquad (3)$$

since ωL is small relatively to e_T, it can be neglected, and we can write for the absolute value

$$I_c\sqrt{[2(R+r)+w]^2+e_T^2}<5 \text{ to 7 volts} \qquad (4)$$

Here and below this is of course not the whole story. Other aspects are the rate of energy dissipation per unit of contact area, or volume, and its duration. Also local short-circuit current. The instantaneous value of current in a path, $I=I_m \sin(\omega t+\theta)$, where I_m is the crest value of the current per armature path, and θ is the point in the cycle at which commutation begins. With the armature in motion the differential equation of commutation may be set up as follows:

For any coil in Figure 1, the electromotive forces or drops in the local circuit b-1-coil-2-b and their directions are

Contact drop between 2 and b = $\dfrac{I_m \sin(\omega t+\theta)-i}{T-t}RT$ (counterclockwise)

Resistance drop in lead to 2 = $[I_m \sin(\omega t+\theta)-i]r$ (counterclockwise)

Resistance drop in coil = iw (clockwise)

Self-inductive drop in coil = $L\dfrac{di}{dt}$ (clockwise)

Speed electromotive force in coil = $I_m e_s \sin(\omega t+\theta)$ (clockwise)

Transformer electromotive force in coil = $I_m e_T \cos(\omega t+\theta)$ (counterclockwise)

Commutation poles will reduce e_s and e_T or even make them negative.

Contact drop between 1 and b = $[I_m \sin(\omega t+\theta)+i]\dfrac{RT}{t}$ (clockwise)

Resistance drop in lead to 1 = $[I_m \sin(\omega t+\theta)+i]r$ (clockwise)

e_s = speed electromotive force in short-circuited coil when I_m = one ampere per path

e_T = transformer electromotive force in short-circuited coil when I_m = one ampere per path

Combining terms gives the Kirchhoff law equation

$$\frac{I_m \sin(\omega t+\theta)-i}{T-t}RT+[I_m \sin(\omega t+\theta)-i]r+$$

$$I_m e_T \cos(\omega t+\theta)=iw+L\frac{di}{dt}+I_m e_s \sin(\omega t+\theta)+$$

$$[I_m \sin(\omega t+\theta)+i]\left(\frac{RT}{t}+r\right) \qquad (5)$$

If it were not for the difficulty and complication, this equation would be integrated to give $i=f(t)$, thence $L(di/dt)$, contact drops and current densities, all as functions

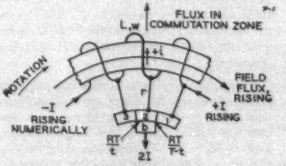


Figure 1

of time, particularly at the last instant when $t=T$. For this last part, the result may be obtained without integration by the following expedient:

At the limit, where i approaches $+I_m \sin(\omega t+\theta)$ and t approaches T, the first

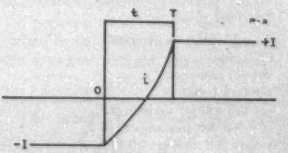


Figure 2

term takes the form 0/0. This may be evaluated by taking the derivatives of numerator and denominator, whence at $t=T$

$$\frac{\omega I_m \cos(\omega t+\theta)-\left(\dfrac{di}{dt}\right)_{T=}}{-1}\cdot RT$$

with this, equation 5 becomes the algebraic expression

$$\frac{\omega i_m \cos(\omega T+\theta)-\dfrac{di}{dT}}{-1}\cdot RT+0+I_m e_T \times$$

$$\cos(\omega T+\theta)=I_m \omega \sin(\omega T+\theta)+L\frac{di}{dT}+$$

$$I_m e_s \sin(\omega T+\theta)+2(R+r)I_m \sin(\omega T+\theta) \qquad (6)$$

This gives for the derivative at the last moment

$$\frac{di}{dT}=\frac{I_m\{(\omega RT-\epsilon_T)\cos(\omega T+\theta)+[2(R+r)+w+\epsilon_s]\sin(\omega T+\theta)\}}{RT-L} \quad (7)$$

or when converting to effective values

$$\left(\frac{di}{dT}\right)_{eff}=\frac{I_{eff}}{RT-L}\times\sqrt{[2(R+r)+w+\epsilon_s]^2+(\pm\omega RT\pm\epsilon_T)^2} \quad (8)$$

At the moment of separation, the electromotive force between, 2 and b

$$e_{spark}=L\frac{di}{dT}+I_m[2(R+r)+w+\epsilon_s]\times\sin(\omega T+\theta)-I_m\epsilon_T\cos(\omega T+\theta) \quad (9)$$

of which the effective value is

$$(e_{spark})_{eff}\cong\frac{RT/L}{RT/L-1}\times\sqrt{[2(R+r)+w+\epsilon_s]^2+\epsilon_T^2} \quad (10)$$

If the armature is at rest, $T=\infty$, and this becomes equal to equation 4. The terms in equation 10 which contains RT/L represent the effect of motion and coil inductance.

Limitations. This derivation neglects effect of nonparallel edges, current and current-density effects, time element in arc and spark phenomena, glowing, ionization, and vapor effects (when sparking occurs, the given differential equation represents the action less accurately), nonconstancy of R, nonconstancy of L (which becomes lower as di/dt increases, because of eddy currents in core iron, etc.), effect of shunt path through rest of armature, saturation, effect of commutator-bar insulation, inequalities of construction, and vibration.

Example. To illustrate the application of the preceding formulas, consider the following values:

$I_{eff}=10$ amperes per path
$r\cong 0$ ohm
$R=0.1$ ohm
$w=0.002$ ohm
$\epsilon_s=0.2$ volt per ampere of I_m
$\epsilon_T=0.4$ volt per ampere of I_m
Brush, 0.2 inch by 1.0 inch, $a=0.2$ square inch
Average effective current density = 100 amperes per square inch
Effective current per brush = 20 amperes
$L=0.00005$ henry
$T=0.001$ second
$\omega=377$ radians per second (60 cycles)
$\omega L=377\times 0.00005=0.0188$ ohm
$2I_{eff}R=2\times 10\times 0.1=2$ volts = drop at one brush
$RT=0.1\times 0.001=0.0001$
$I_{eff}w=10\times 0.002=0.02$ volt

$$\left\{\begin{aligned}&\left(\frac{di}{dt}\right)_{avg}=\frac{2I}{T}=\frac{2\times 10}{0.001}=20{,}000 \text{ amperes per second}\\&L\left(\frac{di}{dt}\right)_{avg}=0.00005\times 20{,}000=1 \text{ volt}\end{aligned}\right.$$

At last moment, for direct current,

$$\left\{\begin{aligned}&\frac{di}{dT}=\frac{10}{0.00005}[2\times(0.1+0)+0.002+0.2]=80{,}400 \text{ amperes per second}\\&(E_{spark})_{t=T}=I\left(1+\frac{L}{RT-L}\right)[2(R+r)+w+\epsilon_s]\\&\quad=10\left(1+\frac{0.00005}{0.0001-0.00005}\right)[2\times(0.1+0)+0.002+0.2]=8.04 \text{ volts}\end{aligned}\right.$$

For alternating current,

$$\left\{\begin{aligned}&(E_{spark})_{t=T}=10\sqrt{\left(1+\frac{0.00005}{0.0001-0.00005}\right)^2[2\times(0.1+0)+0.002+0.2]^2+\left[\left(1+\frac{0.00005}{0.0001-0.00005}\right)\times 0.4+\frac{377\times 0.00005\times 0.0001}{0.0001-0.00005}\right]^2}\\&\quad=10\sqrt{2^2\times 0.402^2+(0.8+0.0377)^2}=11.6 \text{ volts}\end{aligned}\right.$$

The current density = current / area

$$=\frac{I_m\sin(\omega t+\theta)-i}{\alpha\dfrac{T-t}{t}}=\frac{T}{\alpha}\frac{\omega I_m\cos(\omega t+\theta)-\dfrac{di}{dt}}{-1} \quad (11)$$

and

the watts per square inch of contact area = (density) × (R per square inch)

Then for direct current,

$$\left.\begin{aligned}&\text{Density}=\frac{T}{\alpha}\frac{di}{dt}=\frac{0.001}{0.2}\times 80{,}400\\&\quad=402 \text{ amperes per square inch}\\&\text{Watts per square inch}=402^2\times 0.02=3{,}236\\&\text{Watts per brush}=20\times 2=40 \text{ at uniform current density or } 5\times 40=200 \text{ per square inch}\end{aligned}\right\} \quad (12)$$

and for alternating current

the instantaneous and effective densities at the last moment, respectively

$$\left\{=\frac{I_m T}{\alpha}\left\{\left[-\omega+\frac{(\omega RT-\epsilon_T)}{RT-L}\right]\cos(\omega t+\theta)+\frac{[2(R+r)+w+\epsilon_s]}{RT-L}\sin(\omega t+\theta)\right\}\right. \quad (13)$$

and

$$\left\{\begin{aligned}&\frac{I_{eff}T}{\alpha}\left(\frac{1}{RT-L}\right)\sqrt{[2(R+r)+w+\epsilon_s]^2+[\pm\omega L\pm\epsilon_T]^2}\\&=\frac{10\times 0.001}{0.2}\left(\frac{1}{0.1\times 0.001-0.00005}\right)\sqrt{[2(0.1+0)+0.002+0.2]^2+[377\times 0.00005+0.4]^2}\\&=580 \text{ amperes per square inch}\end{aligned}\right. \quad (14)$$

When Brush Covers More Than One Segment. Here a system of as many differential equations as short-circuited coils exists. Because of mathematical difficulties, neither integration nor a process similar to that already given are feasible. Because of this, resort to approximate methods and other viewpoints is necessary, and a variety is possible. A number of these was indicated. Another was given by F. W. Carter in 1909 in the form $RT/\Delta>1$, where Δ is a determinant involving the self- and mutual-inductances of the group of coils short-circuited at a brush. Numerical integration is possible but has been little used.

A. F. PUCHSTEIN (M '27)
(Electrical engineer, Jeffrey Manufacturing Company, Columbus, Ohio)

The Solution of Transient Problems

To the Editor:

There has been a great deal of controversy recently concerning the relative merits of the operational or transform methods and the classical methods of obtaining solutions of transient problems. Professor W. V. Lyon in his article "A Comparison of the Transform and Classical Methods," published in the May 1943 issue of *Electrical Engineering*, pages 198–203, discusses the amount of numerical computation required to determine the transient currents in linear lumped networks by the classical and by the transform or operational method. Professor Lyon points out that in both the classical and the transform method of solution, the characteristic equation of the system must be derived and its roots computed. This is true, and as a consequence, the amount of arithmetical labor involved in the determination of the transient behavior of circuits involving a large number of meshes is so enormous that the analysis of such circuits by these methods is practically impossible.

I wish to point out that there exists still another method which is little known or used by the electrical engineering pro-

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1943 Supplement to Electrical Engineering—Transactions Section

Overvoltage Protection of Current-Transformer Secondary Windings and Associated Circuits

R. H. KAUFMANN
MEMBER AIEE

G. CAMILLI
MEMBER AIEE

Synopsis: It has long been recognized that excessive potentials may be developed in current-transformer secondary windings under unusual conditions, such as open circuits. Recent experience discloses that dangerous overvoltages (several thousand volts) may be produced as a result of normal switching operations on circuits containing lumped capacitance.

A simple procedure for circuit analysis and evaluation of approximate voltage magnitude for the switching transient case is reported. For easy reference, there are included tables of calculated secondary voltage magnitudes covering a broad range of application.

Under certain conditions, overvoltage protection is desirable and important. Aside from the potential hazard to life, current-transformer circuit insulation may be damaged, yet not be evident immediately. Performance at normal rated current may not be noticeably impaired, yet serious failure may occur in the presence of fault-current flow, thus nullifying the action of current-actuated protective relays.

The characteristics of a new overvoltage protector expressly designed for current-transformer protection is presented. With this device current-transformer secondary voltages are limited to moderate values. The protector is small and compact, and easily applied to existing as well as new current-transformer installations. The characteristics are permanent, not affected by repetitive operation, and result in negligible ratio error in the normal operating current range.

Sources of Excessive Voltage

EXCESSIVE potentials in current-transformer secondary circuits may appear as a result of:

1. Open-circuited secondary winding.
2. Switching transients in the presence of lumped capacitance in the power circuits.
3. Fault current flow.
4. Lightning impulse currents.
5. Steep front current transients of other origin.

Open-Circuited Secondary Winding

The circulation of rated current in the primary winding of a current transformer with its secondary winding open-circuited will give rise to a persistent excessive voltage, which may be high enough to be dangerous to apparatus and circuit insulation, as well as to any person who may come in contact with the circuit.

In the absence of secondary current flow, all of the current-transformer primary current is exciting current. Although only a small portion of normal rated primary current is sufficient to saturate the core, there is a short interval each half cycle as the current passes through zero that the magnetic flux is very rapidly whisked from saturation value in one direction to saturation value in the other direction. It is the exceedingly rapid rate of change of flux during this short interval which is responsible for the high open-circuit voltage. The secondary open-circuit voltage magnitude is a function of current-transformer magnetic design, is increased by higher operating frequency, is increased by reduced secondary current rating, but is limited to a maximum value of 1.41 (0.866) (E_L) (R). Potentials in excess of 2,000 volts, with rated primary current flow, may be frequently expected. Figure 2 typifies the resulting peaked voltage wave.

Switching Transients in the Presence of Lumped Capacitance in the Power Circuit

Excessive overvoltages in current-transformer secondary circuits have been observed in connection with the switching of power circuits with which are associated lumped capacitance connected either line to line or line to neutral. A description of the manner in which such voltages are generated, together with a simple procedure for evaluating the probable voltage magnitude, will be of interest.

A de-energized capacitor when switched on to an energized power circuit initially assumes the appearance of a short circuit since the capacitor terminal potential is incapable of being changed instantaneously by any finite amount. It follows that, at the instant the switch is closed, the entire system voltage must be absorbed in the circuit impedance between the capacitor and the source of supply. Current-transformer circuits constitute a part of this interconnecting impedance.

The transition between the initial short-circuit behavior and the normal steady-state normal frequency performance takes the form of a high-frequency oscillation which is rapidly damped by circuit resistance. The physical size of the lumped capacitance has relatively little influence on the transient-voltage magnitude unless small enough to become comparable with distributed capacitance in the interconnecting circuit impedance but does influence directly the frequency of the transient oscillation.

A simple procedure for circuit analysis for evaluating expected current-transformer secondary voltages is contained in Appendix A. It will be noted that the high transient frequency which invariably accompanies the production of excessive current-transformer voltages permits circuit resistance to be ignored. It will be

Paper 43-70, recommended by the AIEE committee on protective devices for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8-9, 1943. Manuscript submitted March 5, 1943; made available for printing March 17, 1943.

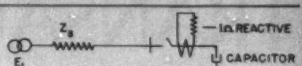
R. H. Kaufmann is in the industrial engineering department, General Electric Company, Schenectady, N. Y., and G. Camilli is research and design engineer, General Electric Company, Pittsfield, Mass.

observed that the current-transformer secondary voltage is influenced prominently by power-circuit operating voltage, power-circuit inductive reactance, current-transformer secondary reactive burden, and current-transformer ratio. It is of particular interest to note that the presence of energized lumped capacitance electrically close to the particular capacitor circuit being switched will usually greatly accentuate the resulting current-transformer secondary voltage.

For quick reference, a tabulation of calculated current-transformer secondary potentials covering a fairly broad range of application conditions has been included in Appendix B. Voltage values to be expected when switching a single lumped capacitance electrically remote from energized lumped capacitance appear in Table I and Figure 8. Calculated voltage magnitudes for the case in which the electrical system contains nearby energized lumped capacitance appear in Table II and Figure 9. It is the purpose of the figure in both instances to portray graphically the relative effect of variation in the predominant influencing factors.

Table I. Calculated Current-Transformer Secondary Voltage e_2 With One-Ohm Reactive Burden

Case 1. Single Circuit Containing Lumped Capacitance*



Current-Transformer Primary Amperes	System Short-Circuit Kilovolt-Amperes	Primary Operating Potential (E_L) Volts			
		13,800	6,900	4,160	2,400
1,200	500,000	87	175		
600		174	348		
300		347	689		
150		684	1,320		
50		1,820	2,750		
1,200	250,000	44	88	145	
600		87	174	289	
300		174	347	574	
150		346	680	1,115	
50		974	1,685	2,560	
1,200	150,000		52	87	150
600			105	173	298
300			208	345	590
150			411	680	1,123
50			1,090	1,710	2,180
1,200	75,000		26	43	75
600			52	86	149
300			105	173	297
150			208	341	581
50			583	938	1,360
1,200	50,000				51
600					100
300					199
150					392
50					990
Current-transformer voltage class		15,000	7,500	5,000	5,000

*These voltages will be produced under short-circuit conditions.

Fault-Current Flow

In the presence of primary-circuit fault-current flow, a corresponding current will flow in the current-transformer secondary winding, which in turn will produce a high current-transformer secondary voltage. Since in the previous case it is reasoned that a lumped capacitance initially appears as a system short circuit, it follows that the same reasoning may be used in judging probable voltage magnitudes in the case of fault-current flow. In general, however, the system impedance will be so large in proportion to that of the current transformer that the voltages produced are not excessive for the insulation of the secondary or the devices connected to it.

It is, however, possible that the presence of energized lumped capacitance may accentuate the resulting transient current-transformer secondary voltage, in the same manner as outlined under the topic of switching transients. It is probable that such accentuated over voltages would be realized only if the character of the electrical fault were such that the transition between a good insulator and a very good conductor was extremely abrupt, an example of which would be the closure of a bolted fault circuit by means of a power-circuit switch.

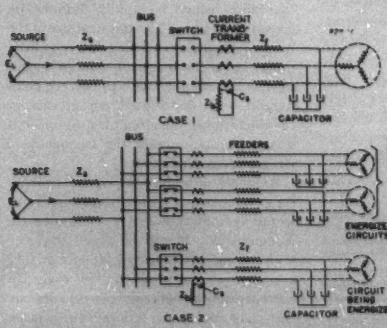


Figure 1 (left). Fundamental circuit arrangements which give rise to high switching transient voltages in current-transformer secondary circuits

Case 1. Single circuit containing lumped capacitance

Case 2. Multiple circuits containing lumped capacitance

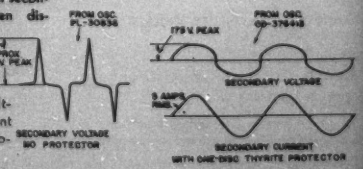


Figure 2 (right). Voltage oscillograms of current-transformer secondary voltage with burden disconnected

Case 1. Secondary voltage, no protector

Case 2. Secondary voltage and secondary current with one disk thyrite protector

Test Verification

To establish the fact that excessive overvoltages could be generated in current-transformer secondary circuits in the manner described in this paper a test setup was made using facilities which could be made available for this purpose. The test circuit arrangement is defined in Figure 4. Closure of the circuit breaker in this test setup produced current-transformer secondary potentials, measured by a calibrated sphere gap, of 9,750 volts, with a reactive burden of 2.96-ohms and 5,150 volts with a reactive burden of 1.74 ohms.

The circuit configuration unfortunately does not simulate closely that encountered in practical circuit operation and is therefore not suited for checking quantitative agreements with theoretical analysis. The tests do serve to establish the following points:

1. Excessive current-transformer voltages may be generated in the manner described in this paper.

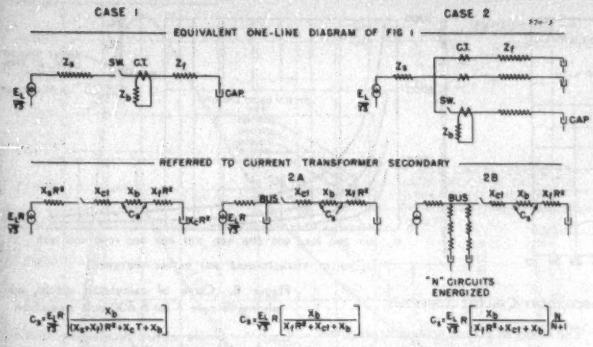


Figure 3. Equivalent-circuit diagram corresponding to Figure 1

2. The generation of such excessive voltages is not contingent on the presence of a high capacity power supply system.

3. Variation in the physical size of capacitor units does not significantly change the magnitude of secondary voltage generated.

Need for Overvoltage Protection

Unless restricted in a suitable manner, in applications iuvolving lumped capacitance, excessive voltages may appear in current-transformer secondary circuits which are dangerous to current-transformer and secondary-circuit insulation and to operating personnel. Secondary-circuit insulation failure assumes particular importance in the case of circuits containing current-actuated protective relays which may be rendered inoperative. Secondary-circuit insulation which has been punctured by excessive transient voltage may not be evident at normal rated current levels but may fail completely when subjected to increased voltages attendant with fault current flow. There is, therefore, a distinct need for an effective reliable overvoltage protector for current transformer circuits.

Protective Equipment

Many overvoltage protective devices which have been applied to current transformer secondary circuits, such as film cutouts, vacuum-tube devices, restricted core designs, and secondary filters, leave much to be desired with respect to initial performance, reliability, simplicity, and application flexibility. In view of the fact that unprotected current-transformer circuits commonly may be subject to recurrent transient overvoltages, it is evident that an adequate protective device must be capable of repetitive operation without change in characteristics, small, compact, and easy to apply, and at the same time be low in first cost.

Table A

Burden	Per Cent Normal Current	Test Without Protector: Ratio	Test Without Protector: Phase Angle	Test With Protector (One Disk): Ratio	Test With Protector (One Disk): Phase Angle
Z (50 volt-amperes at 50 per cent power factor)	10	1.0045	+10	1.0046	+10
	20	1.0025	+ 5	1.0027	+ 5
	40	1.0005	− 2	1.0006	− 3
	60	1.0000	− 4	1.0002	− 5
	100	1.0017	+ 2	1.0019	+ 1
	150	1.0033	+ 5	1.0036	+ 4
	200	1.0043	+ 7	1.0048	+ 5

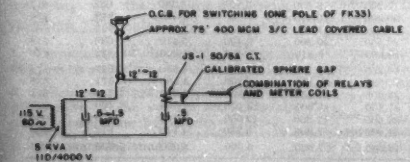
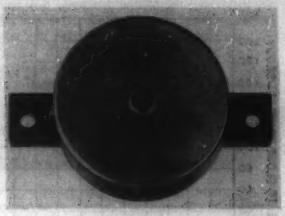

O.C.B. FOR SWITCHING (ONE POLE OF FK331)
APPROX. 75' 400 MCM 3/C LEAD COVERED CABLE
JS-1 50/5A C.T.
CALIBRATED SPHERE GAP
COMBINATION OF RELAYS AND METER COILS
115 V. 60 ~
.5 MFD
5 KVA 110/40000 V.

Figure 4. Diagram of test circuit used to verify production of high switching-transient voltages



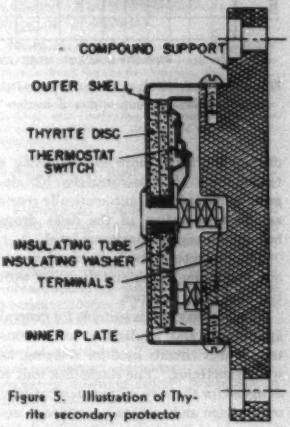


Figure 5. Illustration of Thyrite secondary protector

New Overvoltage Protector

A secondary protector has been developed which meets these requirements. The complete unit is illustrated in Figure 5. The active element embodies one or two disks made of material having nonlinear resistance characteristics and of such character as to secure adequate control of overvoltages, yet avoid objectionable error in secondary currents throughout the operating overcurrent range.

To avoid excessive temperature of the disks in applications which may be subject to secondary open circuit, an auxiliary thermostatic switch is used which short-

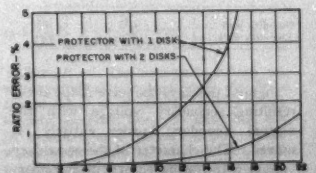


Figure 6. Ratio error caused by Thyrite protector at high currents

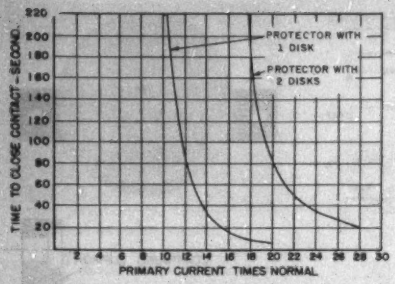


Figure 7. Time to close thermostatic switch contacts at high currents with a Z burden

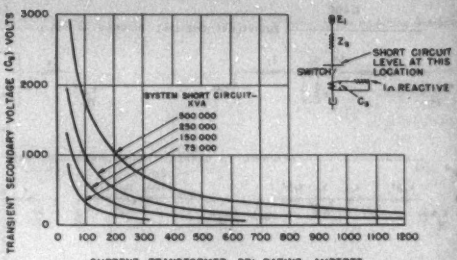


Figure 8. Curve of calculated results applying to case 1 for 6,600-volt operation

Case 1. Single circuit containing lumped capacitance

E_1—6,600-volt three-phase 60 cycles

Current transformer—Instrument-type, five-ampere secondary winding

X_s—One ohm

circuits the active unit upon reaching a temperature of approximately 100 degrees centigrade and automatically resets as the temperature of the disks drops below the assigned maximum level.

The protector is built in two forms—one with a single disk and the other with two such disks in series.

The two-disk unit is suitable for general application and applicable to current-transformer circuits used for relaying, as well as metering. The single-disk unit is designed for the very minimum secondary overvoltage and accepts a sacrifice in accuracy at high currents. It is intended to be used on current-transformer circuits for metering only. The single-disk unit is particularly adapted to operating conditions in which operating personnel frequently contact portions of the current-transformer secondary circuit and current-transformer circuits may easily be inadvertently open-circuited.

Pertinent performance characteristics of the secondary protector are as follows:

Overvoltage

With rated current flowing in the current-transformer primary winding and the secondary burden disconnected, the protector will limit the secondary voltage to the following:

	Rms Volts	Peak Volts
One-disk unit	135	175
Two-disk unit	270	350

Figure 2 portrays the wave shape of the resulting secondary voltage with the normal secondary burden entirely removed. The character of the secondary voltage with the protector is in sharp contrast with that which would be obtained without protector.

Secondary-Circuit Accuracy

The effect of either protector on phase angle and ratio accuracy with a Z burden (50 volt-amperes at 0.5 power factor) is negligible under normal operating conditions between 5 per cent and 200 per cent of rated load current as evidenced by the test information in Table A.

At high currents, the ratio accuracy of the current transformer with the protector connected across its secondary terminals and with a Z burden is shown in Figure 6. Substantial ratio error occurs with currents of 15 times normal and higher with the single-disk protector, which may be objectionable for relaying service.

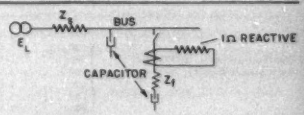
Thermal-Switch Action

The thermal switch is needed only for the purpose of limiting the temperature to a safe value in the presence of an open secondary circuit. Under normal operation, including the temporary flow of fault current, excessive temperature will not be realized and a thermal protective switch if present would not operate. Figure 7 defines the time required for the thermal switch contacts to close as a function of current magnitude, again based on the presence of a Z secondary burden.

The recycling characteristic of the protector with thermal switch in the presence

Table II. Calculated Current-Transformer Secondary Voltage e_s With One-Ohm Reactive Burden

Case 2. Multiple Circuits Containing Lumped Capacitance



Z_f	Current-Transformer Primary Amperes	Primary Operating Potential—Volts					
		13,200	6,600	4,000	2,300	400	220
0.03 ohm per phase Approximately 500 feet Three-conductor cable	1,200	1,053	527	319	183	35	18
	600	2,090	1,045	640	368	70	35
	300	4,040	2,020	1,250	721	138	69
	200	5,770	2,890	1,840	1,060	203	101
	100	8,940	4,469	3,170	1,830	350	233
	50	9,530	4,770	4,200	2,420	462	232
0.012 ohm per phase Approximately 200 feet Three-conductor cable	1,200	2,620	1,310	795	458	88	44
	600	5,130	2,560	1,575	905	173	87
	300	9,460	4,730	3,030	1,740	334	167
	200	12,600	6,300	4,270	2,450	470	234
	100	15,500	7,750	6,310	3,620	695	346
	50	12,300	6,150	6,230	3,590	690	345
0.006 ohm per phase Approximately 100 feet Three-conductor cable	1,200	5,180	2,590	1,585	912	175	88
	600	9,950	4,980	3,100	1,785	342	171
	300	17,200	8,590	5,750	3,300	632	317
	200	20,900	10,470	7,650	4,400	842	420
	150	22,000	11,020	8,770	5,050	965	482
	100	20,550	10,290	9,400	5,410	1,035	518
	50	13,650	6,810	7,460	4,280	822	410
0.003 ohm per phase Approximately 50 feet Three-conductor cable	1,200	10,250	5,130	3,150	1,810	347	173
	600	19,080	9,550	6,100	3,500	671	335
	300	28,900	14,450	10,400	5,970	1,140	574
	200	31,200	15,800	12,650	7,300	1,400	698
	100	24,600	12,300	12,500	7,180	1,375	686
	50	14,400	7,200	8,250	4,740	910	455
Current-transformer voltage class		15,000	7,500	5,000	5,000	5,000	5,000

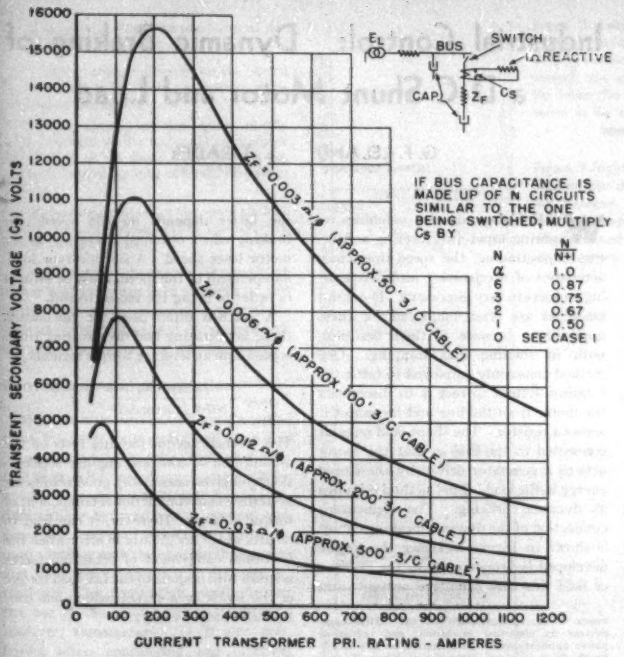


Figure 9. Curve of calculated results applying to case 2 for 6,600-volt operation

E_L—6,600-volt three-phase 60 cycles
Current transformer—Instrument-type, five-ampere secondary winding
X_B—One ohm

of a permanent open-circuited secondary winding and normal rated current flowing in the primary winding is:

	Time to Close Contacts	Time to Reset
One-disk unit	10 seconds	8 minutes
Two-disk unit	14 seconds	11 minutes

Outstanding Advantages

The new secondary protector constitutes a simple, reliable, inexpensive, overvoltage device for general application. It is small, compact, and suitable for direct mounting on the current-transformer structure. The outstanding features are:

1. Permanence of characteristics—not influenced by repetitive operation.
2. Effective voltage protection provided irrespective of the voltage source or the possible oscillation frequencies involved.
3. No operating time lag.
4. Negligible influence on accuracy within the normal range of operating current and burden.
5. Simple, compact, and applicable to existing as well as new current-transformer installations.
6. Active element completely enclosed—mechanical protection provided and dust and other foreign materials excluded.

Appendix A. Current-Transformer Switching-Transient Overvoltage Circuit Analysis

The fundamental circuit arrangements illustrated in Figure 1 are first reduced to an equivalent line to neutral one-line diagram as shown on the upper part of Figure 3.

Refer to Current-Transformer Secondary Winding

A better physical conception of circuit behavior will be gained through analysis in terms of the current-transformer secondary winding. In referring primary circuit quantities to the secondary, voltages are multiplied by R and impedances by R^2. Current-transformer internal impedance is generally available expressed in terms of the secondary winding.

The effective primary circuit voltage is taken as $E_L/\sqrt{3}$ which would correspond to simultaneous closing of the three poles of the switching unit. It might be reasoned that the transient would be controlled by the first two poles to close, in which case the effective primary circuit voltage would be $E_L/2$. As there is no significant difference between the two ($0.577E_L$ and $0.5E_L$), only one (the more pessimistic) will be used.

The resulting equivalent circuits referred to the secondary winding appear in the lower portion of Figure 3.

Evaluation of Secondary Voltage

By neglecting circuit resistance, a tremendous reduction in complexity of analysis is effected. That it is reasonable to do so is judged by the following:

1. At fundamental frequency, resistance generally plays only a minor part in influencing voltage drop through circuit impedance elements.
2. Invariably switching transients which will give rise to dangerous secondary voltages will be associated with oscillating frequencies far above normal which further reduce the significance of resistance.
3. A high degree of accuracy in secondary-voltage evaluation is of slight import. Simplicity in analysis is far more important.

Immediately following circuit closure, system voltage becomes distributed along the inductive reactance between the voltage source and the de-energized capacitor switched on the line. That portion which appears across the current-transformer total secondary burden X_B represents the voltage which appears at the secondary terminals.

Case 1. A single circuit containing lumped capacitance. The expression for current-transformer secondary voltage immediately following switch closure can be directly written.

$$e_S = \frac{E_L}{\sqrt{3}} R \left[\frac{X_B}{(X_s + X_f)R^2 + X_{CT} + X_B} \right]$$

Case 2. Multiple circuits containing lumped capacitance. The treatment of this case will be treated in two steps, *A* and *B*. Case 2*A* assumes the presence of lumped capacitance directly at the distribution bus, while case 2*B* considers a number of similar feeder circuits each containing lumped capacitance, only one of which is de-energized and to be switched on the line.

It will be apparent that an energized capacitor will resist a change in its terminal voltage in the same manner as a de-energized unit. The initial transient distribution of system potential will thus occur across circuit impedance elements intervening between the energized and the de-energized capacitance blocks.

Case 2A. With lumped capacitance at the distribution bus, the supply system impedance Z_S is effectively shunted out of the transient oscillating circuit. The expression for current-transformer secondary voltage becomes

$$e_S = \frac{E_L}{\sqrt{3}} R \left[\frac{X_B}{X_f R^2 + X_{CT} + X_B} \right]$$

Case 2B. The secondary voltage, e_S, when switching one deenergized circuit in the presence of N similar circuits which already energized from the same bus, can be expressed as a fraction of the voltage which would result in case 2*A*. A certain portion of the total system voltage will appear across inductive reactance elements contained in the energized circuits, which

portion will diminish as the number of energized circuits increases. With N energized circuits, the switching of a similar circuit will result in a secondary voltage on the switched circuit of—

$$e_s = \frac{E_L}{\sqrt{3}R}\left[\frac{X_B}{X_f R^2 + X_{CT} + X_B}\right] \times \frac{N}{N+1}$$

$$= e_s \text{ (case 2A)} \times \frac{N}{N+1}$$

Values for the modifier $\frac{N}{N+1}$ are:

N	$\frac{N}{N+1}$
Infinite	1.0
6	0.87
3	0.75
2	0.67
1	0.5
0	See case 1

Nomenclature

Z_s—Primary supply circuit impedance $r_s + jX_s$ ohms per phase (Y)

Z_f—Primary feeder circuit impedance $r_f + jX_f$ ohms per phase (Y)

Z_c—Primary capacitance block impedance $-jX_c$ ohms per phase (Y)

Z_{CT}—Current-transformer internal impedance $r_{CT} + jX_{CT}$ ohms (referred to secondary)

Z_B—Current-transformer secondary burden impedance $r_B + jX_B$ ohms

E_L—Primary circuit-potential—line-to-line volts

e_s—Current-transformer secondary terminal voltage

R—Current-transformer ratio.

Appendix B. Current-Transformer Switching-Transient Overvoltage Calculated Results

For quick estimating purposes, calculations have been made using the methods outlined in Appendix A, covering a fairly broad range of application conditions both for case *A* and case *B*.

All calculated results apply to a five-ampere rated secondary current.

All calculated results are based on a secondary reactive burden of one ohm. For practical purposes, the resulting secondary voltage may be considered directly proportional to X_B.

All results apply expressly to 60-cycle operation. The switching transient is independent of operating frequency, and results here tabulated may be used for other operating frequencies if carefully converted.

Results included under case 1 may be used to judge the secondary voltage magnitude resulting from fault-current flow in a system free of near-by lumped capacitance.

Specific Results

CASE 1

Table I. Tabulated transient secondary voltage for current-transformer primary current ratings ranging from 50 to 1,200 amperes, operating voltages of 13,800, 6,900, 4,160, and 2,400 volts, short-circuit kilovolt-ampere levels from 50,000 to 500,000-kva.

Figure 8. Calculated values for 6,900-volt operation plotted in curve form to illustrate the influence of various factors.

CASE 2

Table II. Tabulated transient secondary voltage of the same character as in Table I.

Figure 9. Values for 6,900-volt operation plotted in curve form to illustrate the influence of various factors.

Typical Circuit Constants

Current-transformer internal series impedance (instrument type):

5,000 volts class $1.+j1.5$ ohms (60 cycles) referred to five amperes secondary windings

7,500 volts class $1.3+j4.0$ ohms (60 cycles) referred to five amperes secondary windings

15,000 volts class $1.3+j4.7$ ohms (60 cycles) referred to five amperes secondary windings

Secondary burden (devices—60 cycles):

Ammeter wattmeter watt-hour meter (*AD*-7 five amperes) $0.05+j0.05$ ohm

Power-factor meter (*AD*-7) $0.11+j0.11$ ohm

Recording ammeter (*CD*-3 five amperes) $0.12+j0.5$ ohm

IAC relay (4–15 amperes on 4-A tap) $0.14+j0.34$ ohm

IBC relay (4–15 amperes on 4-A tap) $0.2+j0.45$ ohm

Power-circuit cable reactance—60 cycles:

7,500 volts and less 0.026–0.033 ohm/1,000: number 1/0 and larger

15,000 volts 0.031–0.039 ohm/1,000: 500,000 cular mils—number 1/0

Industrial Control: Dynamic Braking of a D-C Shunt Motor and Load

G. F. LELAND
NONMEMBER AIEE

L. T. RADER
ASSOCIATE AIEE

WITH high-production machines requiring rapid-duty cycling and accurate positioning, the speed-time characteristics of accelerating and decelerating motors are very important. D-c shunt machines are often employed for these applications because of their flexibility both in starting and stopping. One method commonly employed to bring the rotating system to rest is to disconnect the motor from the line and reconnect it across a resistor. The shunt field remains connected to the line so that the motor acts as a generator driven by the stored energy in the load. This method is known as dynamic braking. The elementary connection of the dynamic-braking circuit is shown in Figure 1. Since the torque developed is proportional to the product of field flux and armature current, and the latter depends on the speed, the braking effect obtained decreases as the motor loses speed. A friction-type load, independent of the speed, must be present in order to bring the motor to rest.

A method often used for calculating these accelerating and decelerating times is based on an average torque formula.[1]

$$T_{\text{average}} = \frac{(WR)^2 (N)}{307.8\ (t \text{ seconds})}$$

This average torque formula rests on the assumption of constant angular acceleration and gives reasonably good results for systems where the frictional component of torque is large. However, it can lead to results which are greatly in error when the frictional component of retarding forces is small with respect to the full load torque of the motor in a system which has considerable stored energy.

Scope of Problem

This paper presents an analysis which leads to an effective and accurate method of calculating the performance of a d-c shunt motor under dynamic braking when connected to various types of load.

Paper 43-74, recommended by the AIEE committees on electrical machinery and industrial power applications for presentation at the AIEE South West District technical meeting, Kansas City, Mo., April 28–30, 1943. Manuscript submitted March 8, 1943; made available for printing March 30, 1943.

G. F. LELAND and L. T. RADER are both in the industrial control engineering department, General Electric Company, Schenectady, N. Y.

The authors acknowledge the assistance of R. R. Lang in checking the equations and making calculations.

References

1. TESTS AND ANALYSIS OF CIRCUIT-BREAKER PERFORMANCE WHEN SWITCHING LARGE CAPACITOR BANKS, T. W. Schroeder, R. W. Boehne, J. W. Butler. AIEE TRANSACTIONS, volume 61, 1942, November section, pages 821–31.

2. ANALYSIS OF FACTORS WHICH INFLUENCE THE APPLICATION OPERATION, AND DESIGN OF SHUNT-CAPACITOR EQUIPMENTS SWITCHED IN LATER BANKS, J. W. Butler. AIEE TRANSACTIONS, volume 59, 1940, pages 795–880.

Three general solutions are covered depending on the type of load.

1. Torque varying directly as the speed together with a frictional component independent of the speed.

2. Torque varying as the square of the speed together with a frictional component independent of the speed, such as for a fan or blower operating with constant discharge orifices.

3. Torque independent of the speed such as a crane hoist operating against gravity, or a wire drawing machine.

This analysis is made only for the shunt motor with constant field strength at full field. The more common applications such as the variable speed d-c motors and the series d-c motors are not discussed.

Conventions and Assumptions

Most authors use the well-known equations $V=e+ir$ for a motor and $e=V+ir$ for a generator so that the direction of current is positive for either machine under normal operating conditions. In order to differentiate between motor current and generator current, subscripts must be used together with the relation that motor and generator current flow in opposite directions. This convention, predicated on the use of the above two equations is, however, unnecessary. It is also confusing when considering one machine which alternately acts as a motor or a generator. The difficulty is eliminated by using only the motor equation $V=e+ir$ together with the following conventions. Positive motor current causes positive motor torque. The direction of rotation of the machine when running as a motor is considered as the positive direction, so that positive torque and acceleration will cause an increase in speed. These relationships are shown in Figures 2 and 3.

The following assumptions are made:

1. Armature reaction is neglected. This assumption is justifiable since dynamic braking currents are usually limited to about 200 per cent full load current and armature reaction is negligible in this range.

2. Frictional forces are assumed constant throughout the entire speed range.

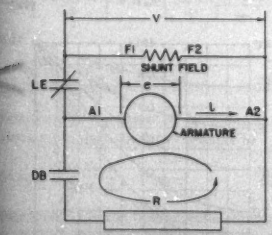


Figure 1. Elementary connection diagram showing dynamic braking circuit

LE—Line contactor
DB—Dynamic braking contactor
R—Total resistance in braking circuit

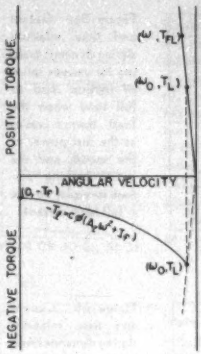


Figure 2 (left). Relations existing before dynamic braking between torque, current, and angular velocity when the load torque varies as the square of the speed

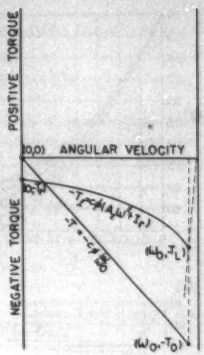
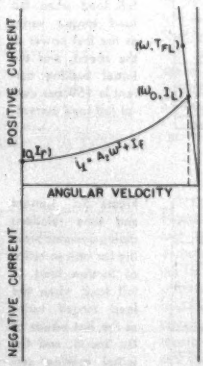
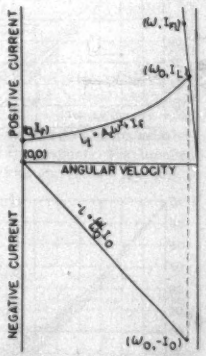


Figure 3 (right). Relations existing after dynamic braking between torque, current, and angular velocity when the load torque varies as the square of the speed





Results

The curves shown in Figures 4 to 8 give the performance of the shunt motor under dynamic braking for the assumed loads. Both coordinates are dimensionless quantities, so that the curves are applicable to any motor and system. The ordinate is the ratio of the current at any instant as a fraction of the initial braking current. When the value of the braking resistor remains unchanged, this ordinate is also a ratio of the speed at any instant to the initial speed. The abscissa is given as a function of the initial watts in the braking circuit, the total mechanical stored energy in the rotating system, and the time.

Although the curves are given for a constant braking resistance, they may be applied when the resistance is decreased in steps during the braking period, provided only that the speed at which the switching occurs is considered full speed, and the new KE_0 is then used.

The parameter, M, is the constant torque component of the armature current as a function of the full load current. It should be noted that when $M=1$, case *b*

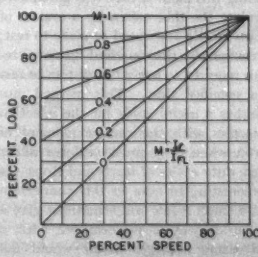


Figure 4. Load torque versus speed for various ratios of friction load to full load when the load torque varies as the first power of the speed

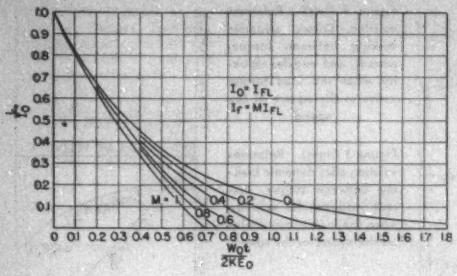


Figure 5a. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the first power of the speed, and the initial braking current is equal to the full load current

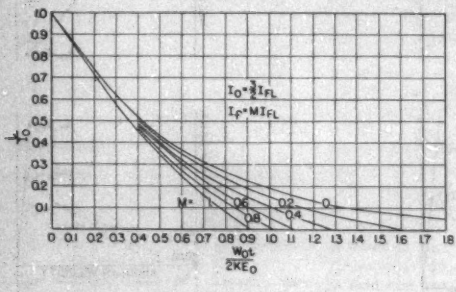


Figure 5b. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the first power of the speed, and the initial braking current is 150 per cent of full load current

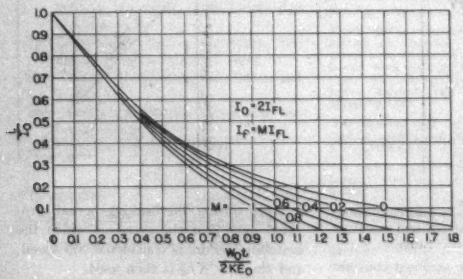


Figure 5c. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the first power of the speed, and the initial braking current is 200 per cent of full load current

and case *c* are identical and reduce to case *a*.

Using this method then it is possible to calculate the time taken by a system of known inertia and speed to come to rest; or conversely the required braking resistor required to bring the system to rest in a specified time. This method also furnishes a useful guide for the selection of motors with the correct moment of inertia when they must perform under severe duty cycles of starts and stops. It is interesting to note in this connection that a small motor will sometimes give a certain duty-cycle performance with a load where a larger motor would fail under the same conditions.

The cases treated cover many of the usual loads encountered in industrial work, but the curves can be extrapolated for other speed torque conditions, or the equations can be set up for any conditions and solved using graphical integration if necessary.

The curves presented for case *b* and case *c* are for dynamically braking a fully loaded motor. Similar curves can be drawn for any other load condition by assigning different values to *b* in equations 15 and 17.

Analysis

(For nomenclature see Appendix I.)

The equation for generated voltage is

$$e = \frac{ZP}{m} \frac{\phi n}{(60)10^8} \text{ volts,}^3 \text{ and since } \omega = \frac{2\pi n}{60}$$

$$e = \frac{c\phi\omega}{2\pi 10^8} \text{ volts} \qquad (1)$$

where $c = ZP/m$. The torque equation[3] is

$$T = \frac{ZP}{m} \frac{\phi i}{20\pi} \text{ dyne-centimeters}$$

and since 10^7 dyne-centimeters = 1 watt-second, this becomes

$$T = \frac{ZP}{m} \frac{\phi i}{2\pi 10^8} = \frac{c\phi i}{2\pi 10^8} \text{ watt-seconds} \qquad (2)$$

The load torque, which is negative, causes a positive armature current to flow (Figure 2), and since positive current has been defined as the current that produces a positive torque, then

$$T_L = \frac{-c\phi i_L}{2\pi 10^8} \text{ watt-seconds} \qquad (3)$$

Now,

$$T + T_L = J\frac{d\omega}{dt} = J\alpha \qquad (4)$$

At time $t = 0$, the line contactor LE shown in Figure 1 is opened and the dynamic braking contactor DB is closed, so that

$$e = -iR = \frac{c\phi\omega}{2\pi 10^8} \qquad (5)$$

Since $KE = {}^1/_2 J\omega^2$ then

$$J = \frac{2KE}{\omega^2} = \frac{2KE_0}{\omega_0^2} \qquad (6)$$

Combining equations 4 and 6 gives

$$T + T_L = \frac{2KE_0}{\omega_0^2}\frac{d\omega}{dt} \qquad (7)$$

Expressing the torques in terms of currents, equation 7 becomes

$$\frac{c\phi i}{2\pi 10^8} - \frac{c\phi i_L}{2\pi 10^8} = \frac{2KE_0}{\omega_0^2}\frac{d\omega}{dt} \qquad (8)$$

From equation 5

$$\omega = -\frac{iR2\pi 10^8}{c\phi} \qquad (9)$$

and since $i = -I_0$ at $t = 0$ then

$$\omega_0 = \frac{I_0 R 2\pi 10^8}{c\phi} \qquad (9a)$$

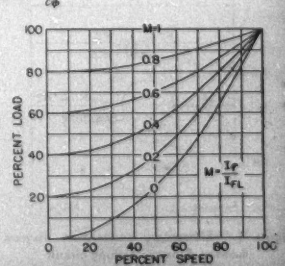


Figure 6. Load torque versus speed for various ratios of friction load to full load when the load torque varies as the square of the speed

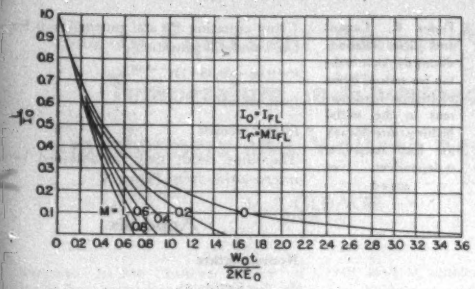


Figure 7a. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the square of the speed, and the initial braking current is equal to the full load current

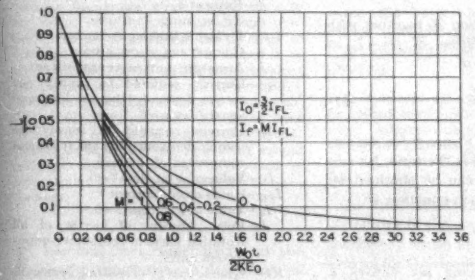


Figure 7b. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the square of the speed, and the initial braking current is 150 per cent of full load current

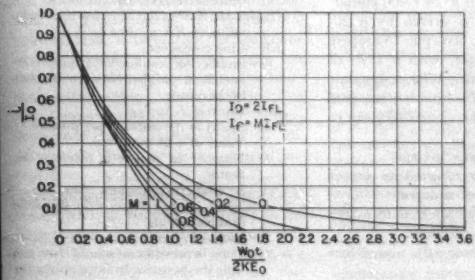


Figure 7c. Current and time relations during dynamic braking for various ratios of friction load to full load when the load torque varies as the square of the speed, and the initial braking current is 200 per cent of full load current

so that

$$\omega_0^2 = \left[\frac{I_0 R 2\pi 10^8}{c\phi}\right]^2 = W_0 R \left[\frac{2\pi 10^8}{c\phi}\right]^2$$

and

$$\frac{1}{\omega_0^2}\frac{d\omega}{dt} = \frac{-c\phi}{W_0 R 2\pi 10^8}\frac{di}{dt} \tag{10}$$

Substituting equation 10 in equation 8 and simplifying, the latter reduces to

$$i - i_L = \frac{-2KE_0}{W_0}\frac{di}{dt} \tag{11}$$

Equation 11 is the fundamental equation governing dynamic braking and can be solved when i_L is known as a function of speed.

CASE I

$i_L = A_1\omega + I_f$

Immediately after switching, $i_L = I_L$, for the speed of $\omega = \omega_0$. Therefore, $I_L = A_1\omega_0 + I_f$. The load current can be expressed in terms of I_{FL} by letting $I_L = bI_{FL}$ where b is the ratio between the two currents.

Therefore, $A_1 = (bI_{FL} - I_f)/\omega_0$ so that

$$i_L = (bI_{FL} - I_f)\frac{\omega}{\omega_0} + I_f \tag{12}$$

After switching to the dynamic braking connection, the armature current at any speed is obtained from equations 9 and 9a yielding, $\omega/\omega_0 = -i/I_0$ so that equation 12 becomes

$$i_L = \left(\frac{I_f - bI_{FL}}{I_0}\right) i + I_f \tag{13}$$

Substituting equation 13 into equation 11 yields

$$\frac{2KE_0}{W_0}\frac{di}{dt} + \frac{(I_0 + bI_{FL} - I_f)}{I_0} i = I_f \tag{14}$$

This is a linear first-order first-degree differential equation whose solution, after substitution of the boundary condition, $i = -I_0$ at $t = 0$ is

$$\frac{i}{I_0} = \frac{I_f}{I_0 + bI_{FL} - I_f} - \left[\frac{I_f}{I_0 + bI_{FL} - I_f} + 1\right] \epsilon^{-\frac{W_0 t}{2KE_0}\left[\frac{I_0 + bI_{FL} - I_f}{I_0}\right]} \tag{15}$$

For the fully loaded motor b is unity, and the equation becomes

$$\frac{i}{I_0} = \frac{I_f}{I_0 + I_{FL} - I_f} - \left[\frac{I_f}{I_0 + I_{FL} - I_f} + 1\right] \epsilon^{-\frac{W_0 t}{2KE_0}\left[\frac{I_0 + I_{FL} - I_f}{I_0}\right]} \tag{15a}$$

Equation 15a is shown plotted in Figures 5a, 5b, and 5c for various percentage values of I_f to I_{FL}. The maximum value of I_0 is usually governed by the commutating ability of the machine. Two hundred per cent full load current is a representative value.

CASE II

$i_L = A_2\omega^2 + I_f$

For conditions immediately after switching where $i_L = I_L = bI_{FL}$ this equation reduces to

$$i_L = \frac{(bI_{FL} - I_f)}{I_0^2} i^2 + I_f \tag{16}$$

Substituting equation 16 into equation 11 yields

$$\frac{2KE_0}{W_0}\frac{di}{dt} - \frac{(bI_{FL} - I_f)}{I_0^2} i^2 + i = I_f \tag{17}$$

Substituting b equal to unity, the solution of equation 17 is

$$\frac{W_0 t}{2KE_0} = I_0^2 \int \frac{di}{(I_{FL} - I_f)i^2 - I_0^2 i + I_0^2 I_f} + \text{constant} \tag{18}$$

The right-hand side of this equation is of the form $\int (dx/X)$ where

$$X = ax^2 + bx + c \tag{19}$$

and the solution[4] depends on the value of the discriminant $b^2 - 4ac$. This term is

$$I_0^2[I_0^2 - 4I_f(I_{FL} - I_f)] \tag{20}$$

Since I_{FL} is a constant, the maximum value of the second term in equation 20 is obtained by differentiating it with respect to I_f which yields $I_f = {}^1/_2 I_{FL}$. Equation 20 then becomes

$$I_0^2[I_0^2 - I_{FL}^2] \tag{21}$$

Considering only the case where $I_0 \geq I_{FL}$

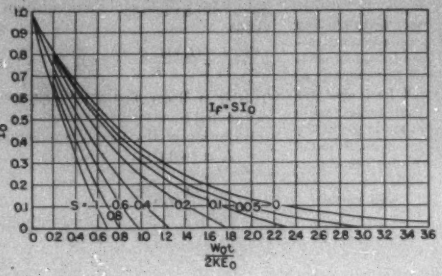


Figure 8. Current and time relations during dynamic braking for various ratios of friction load current to the initial braking current when the load torque is independent of speed

so that the discriminant is positive, the solution of equation 18, after substituting the boundary condition that $i=-I_0$ at $t=0$, is

$$\frac{W_0 t}{2KE_0}=\frac{I_0}{B}\log\left[\frac{2(I_{FL}-I_f)i/I_0-I_0-B}{2(I_{FL}-I_f)i/I_0-I_0+B}\right]\times\left[\frac{2(I_{FL}-I_f)+I_0-B}{2(I_{FL}-I_f)+I_0+B}\right] \quad (22)$$

where

$$B=\sqrt{I_0^2-4I_fI_{FL}+4I_f^2}$$

Letting $I_f=MI_{FL}$ and $I_{FL}=I_0$ equation 22 reduces to

$$\frac{W_0 t}{2KE_0}=\frac{1}{(2M-1)}\log\left[\frac{2(1-M)i/I_0-2M}{i/I_0-1}\right] \quad (23)$$

which is plotted in Figure 7*a* for various values of M. Substitution of $I_f=MI_{FL}$ and $I_0=3/2\ I_{FL}$ into equation 22 gives

$$\frac{W_0 t}{2KE_0}=\frac{3}{\sqrt{16M^2-16M+9}}\times\log\left[\frac{(4M-7+\sqrt{16M^2-16M+9})i/I_0+4M+3+\sqrt{16M^2-16M+9}}{(4M-7-\sqrt{16M^2-16M+9})i/I_0+4M+3-\sqrt{16M^2-16M+9}}\right] \quad (24)$$

which is plotted in Figure 7*b* for various values of M. Substitution of $I_f=MI_{FL}$ and $I_0=2I_{FL}$ into equation 22 gives

$$\frac{W_0 t}{2KE_0}=\frac{1}{\sqrt{M-M^2+1}}\times\log\left[\frac{(M-2+\sqrt{M^2-M+1})i/I_0+M+1+\sqrt{M^2-M+1}}{(M-2-\sqrt{M^2-M+1})i/I_0+M+1-\sqrt{M^2-M+1}}\right] \quad (25)$$

which is plotted in Figure 7*c* for various values of M.

CASE III

$i_L=i_f$

For this constant-torque load condition, equation 11 reduces to

$$i-I_f=\frac{-2KE_0}{W_0}\frac{di}{dt} \quad (26)$$

Integration of equation 26 together with the boundary condition of $i=-I_0$ at $t=0$ gives the solution

$$\frac{i}{I_0}=\frac{I_f}{I_0}-\left(\frac{I_f}{I_0}+1\right)\epsilon^{-\frac{W_0 t}{2KE_0}} \quad (27)$$

which is plotted in Figure 8 for various values of S, where S is the ratio I_f to I_0. This same solution can be obtained by substituting $bI_{FL}=I_f$ in equation 15.

Example

A Thearle balancing set carries a smooth rotor with a WR^2 of 2,400 pound-feet squared. This is driven by a 20-horsepower 230-volt 500-rpm 75-ampere full-load-current motor, with a WR^2 of 21 pound-feet squared. With a dynamic braking resistor of 3.78 ohms, it is required to find the time for the system to come to rest.

Motor speed at test = 584 rpm

WR^2 of test rotor referred to motor shaft = 552 pound-feet squared

WR^2 of two pulleys referred to motor shaft = two pound-feet squared

WR^2 of motor rotor = 21 pound-feet squared

Total WR^2 referred to motor shaft = 575 pound-feet squared

Internal resistance of motor $r=0.3$ ohms

Therefore, total dynamic braking resistor $R=4.08$ ohms so that $I_0=230/4.08=56.4$ amperes.

The steady-state load on the motor is 4.5 amperes and the speed is low enough so that windage can be considered negligible. Then

$$\frac{I_f}{I_0}=\frac{4.5}{56.4}=0.08$$

$$W_0=I_0^2R=(56.4)^2(4.08)=12{,}900 \text{ watts}$$

$$KE_0=(2.31)WR^2N^2\times10^{-4} \text{ watt-seconds}$$
$$=(2.31)(575)(584)^2\times10^{-4}=45{,}200 \text{ watt-seconds}$$

Therefore,

$$\frac{W_0 t}{2KE_0}=0.143t$$

Using equation 27 and putting $i=0$ for the standstill condition

$$0=0.08-(0.08+1)\epsilon^{-0.143t}$$

from which

$t=18.2$ seconds

The same result may be obtained by interpolation from Figure 8.

Appendix

Nomenclature

A_1, A_2—Constants.
b—Ratio of I_L to I_{FL}.
c—ZP/m, motor constant.
DB—Dynamic braking contactor.
e—Counter *emf* at any instant.
i—Armature current at any instant.
i_L—Current required to supply the torque demanded by the load and equal I_f at $\omega=0$.
I_f—Current required to supply the torque demanded by the frictional component of the load.
I_L—Value of i_L at time $t=0$.
I_{FL}—Rated motor current.
I_0—Value of i at time $t=0$.
J—Polar moment of inertia of all Rotating parts in centimeter-gram-second units.
KE—Kinetic energy of rotating system in centimeter-gram-second units.
KE_0—$2.31\ (WR^2)\ (N)^2\ 10^{-4}$ watt-seconds, value of KE at time $t=0$.
LE—Line contactor.
m—number of conductor groups connected in parallel between brushes in the motor.
M—Ratio of I_f to I_{FL}.
n—Speed in revolutions per minute.
N—Value of n at time $t=0$.
P—Number of magnetic poles in the motor.
r—Internal resistance in ohms.
R—Total ohms resistance in dynamic braking circuit.
S—Ratio of I_f to I_0.
t—Time in seconds measured from the time the dynamic braking contactor closes.
T—Developed torque in watt-seconds.
T_L—Load torque in watt-seconds.
V—Line voltage.
W_0—I_0^2R in watts.
WR^2—Inertia in pound-feet squared.
Z—Number of armature conductors.
α—Angular acceleration in radians per second per second.
ϕ—Useful flux per pole crossing the air gap.
ω—Angular velocity in radians per second.
ω_0—Value of ω at time $t=0$.

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Use of Equivalent Annual Ambient Temperature in Overloading Transformers and Voltage Regulators

M. S. OLDACRE
MEMBER AIEE

Synopsis: In the "Interim Report on Guides for Overloading Transformers and Voltage Regulators,"[1] reference is made to the use of equivalent annual ambient temperatures in determining the loading of transformer equipment. This paper is to show a method of calculating the equivalent annual ambient temperature from readily available climatological data to avoid difficulties in other methods that have been proposed. An outline is given also of conditions under which the equivalent annual ambient temperature may be applied in determining permissible overloads for transformers.

IT has long been understood that the life of a transformer is dependent on the operating temperature of its insulation. A great amount of experimental work on aging of insulation has been done in recent years.[2–6] Although there has been no complete agreement on the time-temperature-aging characteristics of transformer insulation, the eight-degree-centigrade rule formulated by V. M. Montsinger has been given general acceptance.

The proposed American Standard *C-57*[7] recommends 95 degrees centigrade as the hottest-spot temperature that will give normal life for continuous operation of a transformer. For rating purposes this is restated as follows:

". . . transformers of usual design having a winding temperature rise (by resistance) of 55C at rated load . . . may be operated continuously at rated load . . . provided that . . . the temperature of the cooling air at no time exceeds 40C and the average temperature of the cooling air during any 24-hour period does not exceed 30C."

For the average transformer, an increase of one per cent in load above 100 per cent increases the hottest-spot temperature rise approximately one degree centigrade. Operation above 100 per cent load at ambient temperatures below 30 degrees centigrade will still not cause the hottest-spot temperature to exceed the limit of 95 degrees centigrade if the following American Standard rule is observed:

"Oil-immersed self-cooled transformers may be loaded continuously one per cent above rated kilovolt-amperes for each degree centigrade that the daily average temperature of the cooling medium (air) is below 30C."

In June 1942, the transformer subcommittee of the committee on electrical machinery issued an "Interim Report on Guides for Overloading Transformers and Voltage Regulators." This report gave a rule for overloading based on low ambient temperatures which included the following statement:

"Under some conditions greater permissible overload capability can be obtained by using 'equivalent annual ambient' instead of the daily average ambient when applying the rule for overloads due to change in ambient. The equivalent annual ambient is the temperature which, if maintained continuously, would result in the same aging as that occurring under the actual ambient temperature throughout the year."

The use of equivalent annual ambient temperature instead of average annual temperature takes into consideration the fact that the average rate of deterioration of insulation for a temperature range is higher than the rate of deterioration for the average temperature in the same range. This is in accordance with the eight-degree-centigrade rule mentioned above.

To calculate an equivalent annual ambient temperature would require the averaging of the aging for all the different ambient temperatures throughout the year. For general use this would have to be done for a period of years in order to arrive at a usable mean condition. Such lengthy calculations have been the chief difficulty in the application of equivalent ambient temperature. This paper presents an approximate method of determining equivalent annual ambient temperature from readily available United States Weather Bureau data. The results are compared with those obtained from complete summaries for a few cities to justify the general use of the approximate method.

Use of Climatological Data

Based on climatological data issued by the United States Weather Bureau, the range of ambient temperature during the year may be divided into three parts, as follows:

1. *Range during the year of monthly mean temperatures.* These are summarized nationally and are readily available.

2. *Range during the month of daily mean temperatures.* These are not summarized nationally, except on a normal basis, but are available locally from annual reports.

3. *Range during the day of hourly temperatures.* These are available nationally as the difference between the normal daily maximum and the normal daily minimum temperatures.

The daily mean temperature is the average of the maximum and minimum temperatures for the day, not the weighted average. The monthly mean temperature is an average of the daily mean temperatures during the month.

For use in calculating equivalent annual ambient temperature, there has been general agreement on the use of items 1 and 2 in the preceding list. There has been disagreement on the use of item 3 on two points, as follows:

(*a*). Present American Standard *C-57* states: "A transformer may be operated continuously at rated load . . . provided that . . . the temperature of the cooling air at no time exceeds 40C, and the average temperature of the cooling air during any 24-hour period does not exceed 30C." To

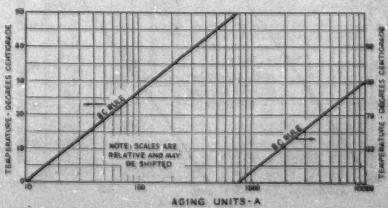
TEMPERATURE - DEGREES CENTIGRADE
TEMPERATURE - DEGREES CENTIGRADE
8 C RISE
8 C RISE
NOTE: SCALES ARE RELATIVE AND MAY BE SHIFTED
AGING UNITS - A

Figure 1. Effect of temperature on aging of transformer insulation

Paper 43-68, recommended by the AIEE committee on electrical machinery for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8-9, 1943. Manuscript submitted February 8, 1943; made available for printing March 4, 1943.

M. S. OLDACRE is equipment and research engineer of the Commonwealth Edison Company, Chicago, Ill.

consider equivalent daily temperature instead of average daily temperature is contrary to this provision of the American Standard.

(b). On a daily temperature cycle the thermal lag of the transformer flattens out the range of hot-spot temperatures to make it less than the range of ambient temperatures.

For these reasons it is believed that the range during the day of hourly temperatures should be ignored in calculating equivalent annual ambient temperature and only items 1 and 2 considered. Furthermore, it was found that the use of item 3 affected the calculated value of equivalent annual ambient temperature by only a small fraction of a degree.

Calculation of Equivalent Ambient Temperature—Direct Method

Accepting as valid the eight-degree-centigrade law formulated by V. M. Montsinger,[3] the life of transformer insulation is halved for every eight-degree-centigrade increase in temperature and, conversely, is doubled for every eight-degree-centigrade decrease. This is expressed by the equation

$$L = Ke^{-0.0866T} \qquad (1)$$

where

L = life of the transformer insulation
T = temperature in degrees centigrade
K = constant chosen to give rated life at rated temperature

Conversely, the rate of aging of transformer insulation per unit time of operation may be expressed by the equation

$$A = K_1 e^{0.0866T} \qquad (2)$$

where

A = rate of aging or aging units consumed per unit time of operation
T = temperature in degrees centigrade
K_1 = a constant chosen to give rated life at rated temperature

For convenient use with climatological reports on a Fahrenheit basis, equation 2 may be rewritten as

$$A = K_1 e^{0.0481T} \qquad (3)$$

where T = temperature in degrees Fahrenheit.

For an example of the use of these formulas, only monthly mean temperatures will be used. Account will be taken of range of daily mean temperatures later. The data for Kansas City, Mo., are given on attached Table I. Column 2 gives monthly mean temperatures. Column 4 gives aging units for these temperatures obtained by substituting the temperature values in equation 2. Since the aging data are to be reconverted to temperature data, the constant K_1 may be taken as unity. The average of column 4 reconverted to temperature by equation 2 gives the equivalent annual temperature, that is, the temperature giving an average monthly aging that would result in the same total aging for the year as for the temperature cycle of column 2. Calculations with equation 3 are shown in columns 3 and 5 of attached Table I.

A graphical solution of the same data may be obtained by plotting equations 2 and 3 as shown in Figures 1 and 2, respectively. Figure 1 is plotted for the eight-degree-centigrade rule by doubling the aging unit abscissa for each eight-degree-centigrade increase in the temperature ordinate. The curve of Figure 2 is plotted in the same manner for 14.4 degrees Fahrenheit. As in the mathematical solution, the value chosen for the constant is unimportant.

Columns 6 and 7 show the use of these curves in obtaining the equivalent ambient temperature graphically. It will be noted that the use of varying constants gives different aging units, but that the temperatures check.

Table I. Calculation of Equivalent Ambient Temperature for Kansas City, Mo.

(Considers Only the Monthly Mean Temperature)

Month	Monthly Average Temperature		$e^{0.0866T}$	$e^{0.0481T}$	A_C Figure 1	A_F Figure 2
	Centigrade (2)	Fahrenheit (3)	Centigrade (4)	Fahrenheit (5)	(6)	(7)
January	−1.3	29.7	0.89	4.17	9	42
February	−0.7	30.8	0.94	4.40	10	44
March	6.2	43.2	1.71	8.00	17	81
April	12.7	54.9	3.01	14.00	30	140
May	18.1	64.6	4.78	22.40	48	225
June	23.3	73.9	7.50	34.95	75	350
July	25.6	78.2	9.15	43.00	91	432
August	24.9	76.8	8.60	40.20	86	405
September	20.8	69.4	6.06	28.20	60	285
October	14.5	58.1	3.51	16.30	35	166
November	7.0	44.6	1.83	8.55	19	86
December	0.7	33.3	1.06	4.95	11	50
Total	151.8	657.5	49.04	229.15	491	2,306
Average	12.7	54.8	4.09	19.1	41	192
Equivalent temperature			16.3	61.3	16.3	61.3

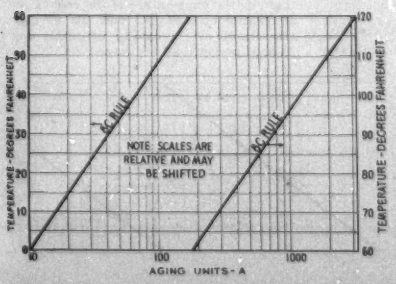

Figure 2. Effect of temperature on aging of transformer insulation

A survey was made of climatological data issued by the United States Weather Bureau for 23 cities in the United States (see Table II). Equivalent annual ambient temperature was calculated by the direct graphical method described above from normal monthly mean temperatures. These data were plotted as divergence K_3 from the average annual temperature as a function of range R during the year of monthly mean temperatures. The results are shown as the K_3 curve on Figure 3.

The effect of range during the month of daily mean temperatures was not calculated nationally because of the prodigious quantity of work required. However, a complete check was made for Chicago and had already been made for six other cities in a recent paper by Hellmund and McAuley.[8] It was found that the true equivalent ambient temperature could be approximated by using the curve K_3 of Figure 3 and adding ten de-

Calculation of Equivalent Ambient Temperature—Approximate Method

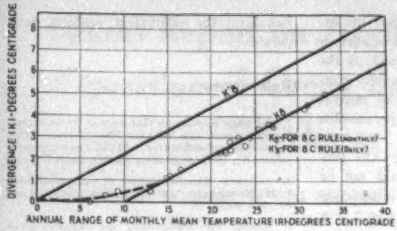
DIVERGENCE (K)-DEGREES CENTIGRADE
ANNUAL RANGE OF MONTHLY MEAN TEMPERATURE (R)-DEGREES CENTIGRADE
K8-FOR B.C. RULE (MONTHLY)
K'8-FOR B.C. RULE (DAILY)

Figure 3. Divergence K between equivalent annual ambient temperature T_e and annual average ambient temperature T_a as a function of annual range R of monthly mean temperature

grees centigrade to the range over the year of monthly mean temperatures. The curve K'_8 is the K_8 curve moved up ten degrees centigrade so that divergence K'_8 between equivalent annual ambient temperature and average annual ambient temperature may be read directly as a function of annual range R.

This adjustment of ten degrees centigrade is no exact value taken from climatological summaries. Reference to Figure 4, in which the data for the Chicago five-year summary are given in curve form, will show the daily mean temperature curve to be very close to the hourly temperature curve. This is because the recorded daily mean is usually higher than the weighted mean, especially in the summer. The difference between the curve of daily mean temperatures and that of monthly mean temperatures is a matter of only a few degrees except at the end points. Any adjustment must take care of both the average difference of a few degrees and this end-point difference. The ten-degree-centigrade adjustment was used because it closely approximates calculated data, and because it gives a curve that is easily and conveniently used with the readily available monthly mean data. Thus, if

1. July average temperature = 25 degrees centigrade
2. January average temperature = −5 degrees centigrade
3. Annual average temperature = 10 degrees centigrade

then annual range

R = 30 degrees centigrade
K'_8 = 6.5 degrees centigrade
T_a = 16.5 degrees centigrade

For six cities[8] the equivalent ambient temperature had already been calculated by the direct method from summaries of hourly temperatures for the six-year period of 1932–37, inclusive. Similar calculations were made for Chicago for the period of 1937–41, inclusive. The results were then compared with the approximate values of equivalent temperature from Table II, column 8. A preliminary check-up had shown a difference between normal annual mean temperature and mean temperatures for the period covered by the summaries. It was necessary to adjust the direct calculations for this difference. The results are shown in Table III. It can be seen that the correlation between results by the two methods is within the accuracy of the problem as a whole.

The methods described above for obtaining equivalent annual ambient for air-cooled transformers may be applied to water temperature for water-cooled transformers. This is especially applicable when the cooling water is obtained from a lake or river so that there is a considerable annual range in water temperature. For Lake Michigan water used in Chicago, the averages of the monthly maximum temperatures over a 15-year period were used to give the annual temperature cycle. The equivalent temperature obtained by using Figure 1 checked very closely with that obtained from use of K_8 in Figure 3.

Table II. Equivalent Annual Ambient Temperature

City	Annual Average Temperature (T_a) (2)	Based on Monthly Mean Temperatures: Annual Range (R) (3)	Equivalent Annual Ambient Calculated (T_e) (4)	Divergence (K_8): Calculated (5)	Divergence (K_8): From Figure 3 (6)	Based on Daily Mean Temperatures Using K'_8 of Figure 3: (K'_8) (7)	(T_a) (8)
Bismarck	4.7	35.0	10.0	5.3	5.4	7.6	12.3
St. Paul	6.8	33.1	11.8	5.0	5.0	7.1	13.9
Duluth	3.3	31.1	7.8	4.5	4.5	6.7	10.0
Des Moines	9.7	30.7	14.0	4.3	4.5	6.6	16.3
Chicago	9.5	27.1	13.0	3.5	3.7	5.8	15.3
Kansas City	12.7	26.9	16.3	3.6	3.7	5.8	18.5
St. Louis	13.3	26.5	16.9	3.6	3.6	5.7	19.0
Helena	6.2	25.3	9.6	3.0	3.3	5.5	11.7
Boston	9.8	24.3	12.8	3.0	3.1	5.2	15.0
New York	11.3	23.8	13.9	2.6	2.9	5.1	16.4
Denver	10.0	23.0	13.0	3.0	2.8	5.0	15.0
Santa Fe	9.3	22.2	11.7	2.4	2.7	4.8	14.1
Memphis	16.4	22.1	19.2	2.8	2.7	4.8	21.2
Dallas	18.4	21.6	20.7	2.3	2.5	4.7	23.1
Phoenix	21.1	21.5	23.5	2.4	2.5	4.6	25.7
Raleigh	15.6	20.9	17.9	2.3	2.3	4.5	20.1
Galveston	20.9	16.5	22.3	1.4	1.4	3.5	24.4
Portland, Oreg.	11.7	15.2	12.9	1.2	1.2	3.3	15.0
Jacksonville	20.7	14.8	21.8	1.1	1.1	3.2	23.9
Seattle	10.6	13.1	11.1	0.5	1.0	2.8	13.4
Los Angeles	16.8	9.2	17.3	0.5	1.0	2.0	18.8
Key West	24.9	7.8	25.2	0.3	1.0	1.7	26.6
San Francisco	13.4	6.1	13.4	0	1.0	1.8	14.7
Average	12.9	21.6	15.5	2.6	2.7	4.7	17.6
National mean	12.3	22.8	14.9	2.6	2.8	4.9	17.2

All temperatures are in degrees centigrade.

Application to Transformer Loading

For constant load over the year or for an annual load cycle that has its maximum in summer, the maximum permissible load for normal life can be based on the equivalent annual temperature of the cooling medium obtained by the methods herein described. This is applicable both to water-cooled and to air-cooled transformers. The increase in loading for reduction in ambient temperature for

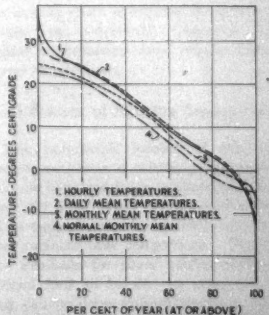
TEMPERATURE-DEGREES CENTIGRADE
PER CENT OF YEAR (AT OR ABOVE)
1. HOURLY TEMPERATURES.
2. DAILY MEAN TEMPERATURES.
3. MONTHLY MEAN TEMPERATURES.
4. NORMAL MONTHLY MEAN TEMPERATURES.

Figure 4. Outdoor ambient temperatures, Chicago, Ill. (From U. S. Weather Bureau data, 1937–41, inclusive)

Table III. Equivalent Ambient Temperature—Comparison of Direct and Approximate Methods

City	Annual Average Temperature	Equivalent Annual Temperature: Direct Method: Calculated[a]	Equivalent Annual Temperature: Direct Method: Corrected to Normal[a]	Equivalent Annual Temperature: Approximate Method from Figure 3
Bismarck	4.7	14.7	13.6	12.3
Helena	6.2	12.9	12.1	11.7
Kansas City	12.7	20.1	19.2	18.5
Denver	10.0	16.2	15.0	15.1
Dallas	18.4	22.0	21.6	23.1
Santa Fé	9.3	14.0	13.4	14.1
Chicago	9.5	15.2	14.3	15.3
Average	10.1	16.4	15.6	15.7

All temperatures are in degrees centigrade.

[a] Calculations are based on six- and five-year summaries. Correction is made for difference in mean temperature between summary period and normal.

self-cooled transformers according to American Standard *C*-57 is one per cent for each degree that the temperature is below 30 degrees centigrade. For the temperature data given above, the equivalent annual ambient was 16.5 degrees centigrade, or 13.5 degrees below the standard ambient temperature. Therefore, the permissible constant load throughout the year would be 113.5 per cent of rated load, with normal life expectancy. However, if the average monthly temperature were used as the basis of increased loading, the July average ambient temperature of 25 degrees centigrade would limit the permissible overload to 105 per cent.

For other types of loading, the procedures herein described would not be directly applicable without adaptation to each specific loading condition.[9] For example, for a constant load occurring only a few hours each day, it would be feasible to consider the mean ambient temperatures for those hours rather than for the entire day. When winter and summer loads are not the same, it would be feasible to calculate an annual aging curve based on a combined load and temperature cycle in order to fix the maximum level of the annual load curve as a whole.

Conclusion

The approximate method herein described may be used to obtain equivalent annual temperature from readily available climatological data. For loading on an annual basis the maximum permissible load for normal life can be based on the equivalent ambient temperature.

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Interim Report on Application and Operation of Circuit Breakers and Switchgear

AIEE COMMITTEE ON PROTECTIVE DEVICES
Subcommittee on Circuit Breakers, Switches, and Fuses

THE present war emergency makes it necessary that maximum use be made of existing equipment and that a minimum amount of critical materials be used for new equipment. The following guides have been prepared as an aid to those involved in the application and operation of circuit breakers and switchgear.

This report is intended to cover equipment of the following types:

1. A-c power circuit breakers above 600 volts, both indoor and outdoor.
2. Air disconnecting switches.
3. Switchgear assemblies.

Basis of Design of Apparatus

The name-plate rating of apparatus does not necessarily indicate the load which can be carried safely under all conditions. It specifies the load which may be carried without exceeding the specified temperature rise. However, it is the total temperature and the duration of such temperature which determine the life of apparatus. Obviously the total temperature depends not only on the loading but on the ambient temperature as well.

The present standards for circuit breakers and switchgear provide that the temperature rise of the contacts shall not exceed 30 degrees centigrade at rated load and that the apparatus shall be suitable for continuous operation at rated load, provided the ambient temperature does not exceed 40 degrees centigrade for apparatus with plain copper contacts or 55 degrees centigrade if the contacts and other connections are silver or equivalent. This means that the total temperatures should not exceed 70 degrees centigrade for plain copper or 85 degrees centigrade for silver contacts.

It should be noted that the temperature rise of contacts may increase as a result of oxidation of the contact surface, and, therefore, the standards are based on sufficient maintenance to keep the temperature rise within specified limits.

Effect of Ambient Temperature

It is apparent that, if the ambient temperature is higher than these values, the loading must be less than the name-plate rating to avoid exceeding the permissible total temperature. It is also apparent that if the ambient temperature is lower than these values, the loading may be greater than the name-plate rating. The loading should be reduced approximately two per cent for each degree that the ambient temperature is above these values, and in some cases it may be increased as much as one per cent for each degree that the ambient temperature is below the values specified in the standards. See Figure 1 for relation between loading and ambient temperature for apparatus with silver contacts. These factors should not be used to increase the loading more than 30 per cent without special consideration.

The foregoing recommendations may be applied for average conditions, but they do not represent necessarily the maximum in all cases. This is due to the variations in thermal characteristics of different designs and sizes of switching equipment and variations in types of installation. Therefore, to determine the maximum carrying capacity of individual installations, studies or tests should be made to establish the proper relation between loading and ambient temperature. This is particularly true in the case of heavy current installations.

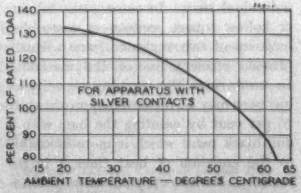

Figure 1. Relation between loading and ambient temperature

Artificial Cooling

Artificial cooling may be used to increase the permissible loading in some installations. This may take the form of forced ventilation of the room in which the apparatus is located, or it may involve forced ventilation through the equipment itself. For oil-filled equipment there may be some possibility of artificial circulation of the oil to assist in the transfer of heat and thus increase the permissible loading. Extreme care must be used in any application of forced cooling to be sure that there are no parts of the equipment which do not benefit by the forced cooling and might reach excessive temperatures. It should be recognized that forced ventilation may tend to increase the danger of fire spreading to other parts of the installation.

Emergency Loading

Under emergency conditions the permissible loading may be higher than under normal conditions, particularly if the duration is not too long and if the condition does not recur frequently. It is impracticable to assign specific values for all types of switchgear. The characteristics of the specific apparatus involved should be thoroughly investigated in connection with the determination of limitations of emergency loading. Also, the heating effect of external connections should be considered. Operation at higher temperatures may require additional maintenance.

Modification of Existing Equipment

The permissible loading of existing circuit breakers and switching equipment may be increased in many cases, particularly the older types of equipment with plain copper contacts, by silver plating the contacts and connections. Means are available for silver plating with a special form of brush. In many cases this can be done without removing the parts or even disturbing the adjustment of circuit breakers and switches. If the loading is increased by resorting to such

Paper 43-69, recommended by the AIEE committee on protective devices for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8-9, 1943. Manuscript submitted March 1, 1943; made available for printing March 8, 1943.

Personnel of subcommittee on circuit breakers, switches, and fuses: R. T. Henry, *chairman*; A. E. Anderson, H. D. Braley, O. E. Charlton, F. W. Cramer, W. Deans, W. S. Edsall, F. R. Ford, H. W. Haberl, H. J. Lingal, L. R. Ludwig, J. B. MacNeill, H. H. Marsh, Jr., J. R. North, H. V. Nye, M. S. Oldacre, H. H. Rudd, R. M. Smith, H. P. St. Clair, H. E. Strang, H. R. Summerhayes, J. D. Wood.

treatment, care must be used to insure against excessive temperatures in other parts of the apparatus. Various papers[6,7,8] indicate some of the possibilities along this line.

The interrupting capacity of existing circuit breakers can be increased in many cases by the installation of new contact systems involving oil blast, deion grids, ruptors, and so forth, together with other parts as necessary, depending upon the type of breaker and its manufacturer.

Current transformers should be carefully considered to determine their actual carrying capacity. Many current transformers are capable of carrying more than their rated load continuously, and most of them can carry short-time emergency loads higher than their rating. "The Interim Report on Transformers"[5] gives useful information in this connection. Studies or tests should be made to determine the maximum carrying capacity of individual installations.

Fuses generally do not have excess current-carrying capacity corresponding to most other devices in that they are fundamentally a thermal overload protective device and accordingly cannot be given overload ratings. In the application of fuses where selective operation is involved, consideration should be given to the effect of ambient temperature on the characteristics of the fuses.

Simplification of New Installations

In selecting equipment for new installations every effort should be made to use the minimum amount of critical materials. Probably the greatest saving can be made by choosing a simple scheme of connections using the minimum amount of equipment consistent with the requirements. Duplication of busses and switching equipment may be avoided in many cases, at least for the duration of the present emergency. The margin between the rating of apparatus and the actual load may be less than might be considered satisfactory under normal conditions.

Where additions are to be made to existing installations of two-bus design, it may be feasible to connect the new circuits to only one of the busses, at least during the emergency. Equipment for such additions may even be obtained by removing some of the existing connections to one of the busses.

The short-circuit current may be kept low in many cases by sectionalizing or other means to permit the use of smaller circuit breakers or existing circuit breakers which might not be satisfactory under normal conditions after the emergency is over.

A large circuit breaker of adequate interrupting capacity may be used in some cases as a backup for a group of smaller circuit breakers, with the protective relay system designed to permit automatic operation of the individual small breakers on faults within their interrupting capacity but locking out and transferring the operation to the large circuit breaker on faults exceeding the interrupting capacity of the small circuit breakers. In such cases the momentary rating of the small circuit breakers should be carefully considered.

In some cases it may be possible to open one or more of the supply circuits in order to reduce the interrupting duty to a value which the otherwise inadequate circuit breakers are capable of interrupting.

In transformer substations with a single transformer bank it may be permissible to omit the circuit breaker on either the high-voltage or the low-voltage side.

In laying out new switching structures the cross section of the busses may be reduced for part of their length by grouping the heavier circuits close to each other and placing the lighter circuits toward the ends of the bus in some cases.

It may be possible in other cases to locate the main incoming circuit near the center of the bus to permit tapering the bus toward the ends.

In outdoor structures it may be possible to use galvanized iron pipe for conductors instead of copper tubing or to substitute other forms of steel for copper conductors in many cases.

In the cases of busses designed to carry heavy current, appreciable amounts of material may be saved by proper consideration of the configuration of the material used. When flat bars are used, the heat dissipating qualities will be considerably improved if the bars are placed on edge rather than flat in order to improve the ventilation. When multiple flat bars are used, consideration should be given to the proper spacing to improve the division of current between the individual bars. In some cases tubular or hollow square sections or assemblies built up of two angles to form a square provide efficient use of the materials. In some cases the carrying capacity of bus bars may be increased approximately 10 per cent by painting the bars with a dull black paint which is more favorable to the emission of heat than a bright surface. Various papers and publications[1,2,3,4] cover the design of busses for heavy current.

Tinning or silver plating all contacts will permit satisfactory operation at higher temperatures than would be the case with plain copper contacts.

Where multiple cables are employed in high-capacity circuits, careful attention should be given to the physical arrangement in order to divide the current evenly between the various cables. It should be noted that the configuration of multiple cables in a flat spacing may result in the outer cables carrying more than their share and the inner ones carrying less than their share of the total current. In some cases this condition can be greatly improved by the installation of small "doughnut type" reactors around the cables which tend to carry the most current.

Wood structures may be used instead of steel. These may be permanent structures in some cases and even greater savings may sometimes be made by using temporary wood structures with a bare minimum of equipment which might not be considered satisfactory for normal conditions after the present emergency is over. Obviously simple temporary structures should be used where there is a reasonable possibility that the use may be limited to the duration of the emergency.

In the interior wiring of new plants the more general use of higher distribution voltages may result in appreciable savings of critical materials. Consideration should be given to using 600 volts instead of 480, and 480 volts instead of 240.

Reactive current is a very important consideration both in industrial plants and in utility systems. Appreciable savings may be made in many cases if the reactive current is supplied at the load rather than from the utility system. Supplying the reactive current at the load results in less voltage drop, less energy loss, and releases system capacity which may be needed to carry other useful load. In many cases the reactive current can be supplied at the load by using synchronous motors, synchronous condensers, or capacitors.

Capacitors may be used to make appreciable savings of critical materials, particularly if they are scattered and connected as near as possible to the various loads. In fact, capacitors connected directly to the leads of each motor should be considered, at least for all but the very small motors. Considerable savings may often be made in the plant wiring in this way. It may be desirable or necessary in some cases to make provision for disconnecting the capacitors during light load periods.

New Developments in Potential-Transformer Design

G. CAMILLI
MEMBER AIEE

Synopsis: This paper describes certain design ideas applied to potential transformers to accomplish substantial reductions in volume and weight, with improved reliability and with better accuracy than the best requirements of the American Standards. The size of these units is such that they appear mostly as bushings.

Perhaps the most striking feature of construction is the arrangement and the insulation of the high-voltage winding. Liquid-impregnated porous paper has been substituted for the combination liquid and solid used in the conventional designs. Another notable improvement incorporated in these transformers is the elimination of all gaskets. The amount of liquid insulation required is extremely small, and therefore premium insulating liquids (such as the Askarels) can be used without much additional expense.

IN the past, the design of liquid-filled potential transformers, perhaps with the exception of the cascade connected units[1] has followed very closely that of power transformers. Thus, until very recently, a 69-kv potential transformer was designed and built essentially according to the same principles and practices as followed in the design of a 69-kv small distribution transformer, with the result that the units were bulky, and their size and weight were out of proportion with their operating duties. A comparison of the new with the old is given in Table I in which it will be seen that the new units are a little over 40 per cent of the weight of the older ones.

Paper 43-71, recommended by the AIEE committee on electrical machinery for presentation at the AIEE North Eastern District technical meeting, Pittsburgh, Mass., April 8-9, 1943. Manuscript submitted February 18, 1943; made available for printing March 8, 1943.

G. CAMILLI is development engineer with General Electric Company, Pittsfield, Mass.

The author acknowledges the assistance of several of his associates, particularly J. J. Vienneau.

Principles of Design

High-Voltage Winding

The high-voltage winding of the new potential transformers is the concentric layer-wound type, shown in Figure 1 for a transformer for connection between line and ground.

This type of construction consists of a plurality of layers of winding and shields so disposed as to give uniform voltage distribution. The innermost layer adjacent to the low-voltage winding starts from the neutral and the successive layers are connected in series progressively, the outermost layer being connected to the line. This winding is placed between two cylindrical shields; one is connected to the innermost layer and eventually to ground, while the other shield surrounds the last (outermost) layer and is connected to the line.

With this arrangement properly proportioned, the relative position of each part of the winding in the electrostatic field between the two shields will not deviate greatly from its actual low-frequency position. Thus, when an impulse voltage is imposed on the line end, it will be substantially uniformly distributed throughout the winding, regardless of the steepness of the oscillation of the applied wave. It is obvious, therefore, that the insulation between the shields and the adjacent layer and between successive layers is only that required to withstand the voltage developed within the individual layers.

Scheme of Design for Cascade Connection

One practical scheme of reducing the size and weight of those transformers which are normally used for operation between line and neutral of a solidly grounded system is by means of the so-called cascade connected units.[1] In this design the insulation can be distributed to the best advantage.

Figure 2 shows the multilayer type of winding construction as is ordinarily used in a cascade potential transformer.

The deciding factors between the single-stage and cascade potential transformers are the economy and accuracy.

In general, the accuracy of the cascade potential transformer is not as great as that of the single-stage type. For voltages higher than 115 kv, it appears that the cascade type is somewhat more economical than the single-stage.

Scheme of Design for Isolated Operation

Figures 3 and 4 show the multilayer type of construction which could be used for a fully insulated transformer for connection from line to line of an isolated system.

In Figure 3 only one high-voltage coil section is used. This type of construction may be applied only to relatively low voltages because of difficulty which is

Conclusions and Cautions

From the foregoing it is apparent that the loading on existing equipment may be increased in many cases and that new equipment may be selected with a view to using a minimum of critical material during the present war emergency. Other suggestions and more details may be found in the papers and publications listed at the end of this report.

It must be recognized that the loading on equipment should not be increased without a thorough study of the limitations of the apparatus involved and of associated equipment such as cables, terminals, current transformers, soldered connections, and so forth. It must also be recognized that increasing the loading on equipment is almost certain to require more maintenance and may shorten the life of some apparatus, but it is undoubtedly true that appreciable savings of critical materials can be made without sacrificing life unduly and without requiring excessive maintenance.

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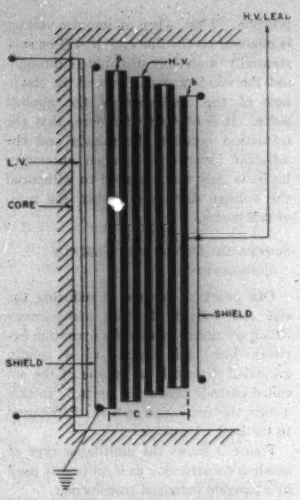


Figure 1. Transformer for operation between line and grounded neutral

encountered in bringing out the high-voltage terminal at the beginning of the high-voltage winding.

For this reason, the scheme shown in Figure 4 is preferred. In this case, the high-voltage winding is divided in two equal sections which are connected together at starting ends of the windings. Each section is of the concentric multilayer type similar in all respects to the arrangement shown in Figure 3, except that the spacing between the inner shield and the low-voltage winding is, of course, designed to withstand a test voltage equivalent to the full line-to-line voltage.

Novel Method of Insulating the High-Voltage Winding

The new method of insulating the high-voltage winding is shown, schematically, in Figure 6. To make the matter more clear, let us compare the new with the old. In potential transformers of the conventional type, the distance between the high-voltage and low-voltage winding of, say, a 138-kv line-to-line connected potential transformer has been essentially the same as the distance between the high-voltage and low-voltage windings of a power transformer of the same voltage rating. Furthermore, in a power transformer this insulating distance in general consists of one or more liquid ducts interleaved with solid insulating barriers. This same type of insulation (liquid ducts plus solid barriers) is used between the high voltage and the core. In a power transformer the liquid ducts have a useful function, the cooling of windings. Such duty is not required in a measuring transformer, because the losses, under ordinary conditions, are negligibly small. A simple calculation of I^2R loss in the high-voltage, or primary, winding of a 138-kv potential transformer may be of interest to those not familiar with the problem. Let us assume that the resistance of such winding is 10,000 ohms. The copper loss at 500 volt-amperes (which is the normal rating of a potential transformer) is then

$$\left[\frac{\text{Output volt-amperes}}{\text{Primary winding volts}}\right]^2 R = 0.13 \text{ watt}$$

which is a very negligible quantity. It is apparent then that the cooling of the high-voltage winding is of secondary importance, and it is, therefore, not necessary to have any liquid ducts. It is well recognized that, in an insulating structure comprising oil operating in series with solid insulation, the dielectric stress is inversely proportional to their dielectric constants, and ordinarily the solid insulation is not effectively utilized.

In the new design, the complete insulating structure consists of solid insulation which is impregnated with an insulating liquid. This combination may be considered a uniform insulating mass having a dielectric constant intermediate between that of the liquid and solid insulation, and its dielectric strength approaches the impregnated paper of an oil-filled cable.

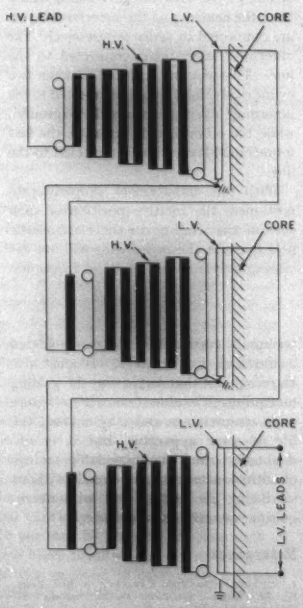


Figure 2. Transformer for operation between line and grounded neutral (cascade type)

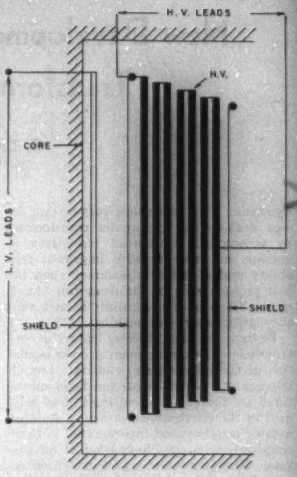


Figure 3. Transformer for operation between lines

Referring now to Figures 4 and 5, the insulation between layers is easily provided for. This may consist of several sheets of paper having folded edges with the layers located between the folds. Such a construction leads to a coil having a small radial thickness. The shield and successive layers give a very good distribution of voltage stress so that the insulation between layers is well proportioned to the stress. This type of construction would be very desirable if the dielectric stresses at the ends were not distributed between the liquid and solid insulation. As has been discussed previously, this condition gives rise to inefficient use of insulation.

Referring to Figure 5, one method of insulating the ends of the layer of the coil would be by the use of very wide folds in the layer insulation and by the use of stepped pressboard barriers as shown. Such an arrangement, however, is not very efficient since the path A from the shield to ground is, in effect, outside the uniform voltage distribution dictated by the high-voltage winding and therefore to avoid creepage failures must be made unnecessarily long.

The good advantages of the cylindrical layer-wound coil, therefore, would be lost unless some more efficient method is found to insulate the ends of the winding. The

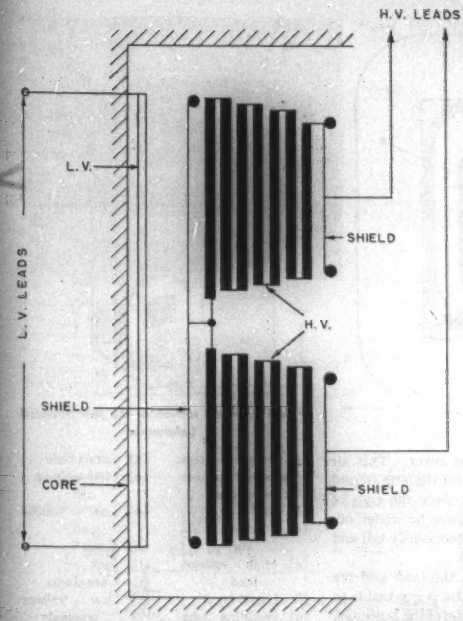


Figure 4. Transformer for operation between lines

scheme shown in Figure 6 seems to offer a good solution to this problem. In this method, the layer insulation consists of paper with folded edges and additional layers of paper. The width of the latter is much longer than the width of the winding layer. After the coil is wound, the extensions of the paper are folded over the shield as shown in the illustration. It will be noted that such a method of insulation not only solves the problem of insulating the ends of the coil, but automatically provides the necessary solid insulation between the line shield and the core (ground) (path *B* of Figure 5).

In using the method of insulating shown in Figure 6, the coil design is so arranged that the insulation at the ends of the winding cuts the electrostatic line of force at right angles and at approximately equipotential steps, thereby realizing all the benefits of cascading the voltage. The application of this type of insulation to transformers with both bushings isolated is shown in Figure 7. The high-voltage coil is divided in two sections *A* and *B*. Each coil is insulated in the same manner as illustrated in Figure 6; pressboard barriers are placed between the two sections, and the entire coil assembly is covered with layers of paper. Thus, oil ducts of previous designs are completely replaced by solid insulating material, and, in a manner similar to the current transformers described in another paper,[2] the entire electrostatic field contains liquid-impregnated porous paper of uniform permittivity.

Such a method of insulation with closely wound and insulated coils has, of course, required the development of a new treatment and impregnating process.

By carefully controlled materials and methods, a very flat power-factor temperature curve is obtained, and any danger of thermal instability is eliminated.

Impulse Characteristics of the High-Voltage Coil Shown in Figure 7

Experimental data and theoretical study (see Appendix) have shown that when this type of high-voltage winding is subjected to impulse voltages with vertical front waves under the worst conditions, approximately 75 per cent of the total voltage appears across one section. Contrary to the behavior of the winding of conventional design, this voltage is approximately uniformly distributed among successive winding layers, and therefore at no point within the high-voltage winding is it necessary to provide insulation to withstand more than the proper share of the voltage appearing across half the winding.

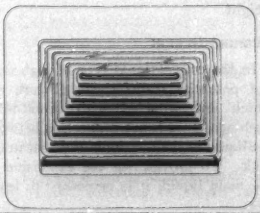


Figure 6. Improved method of insulating the high-voltage winding (for grounded neutral transformer)

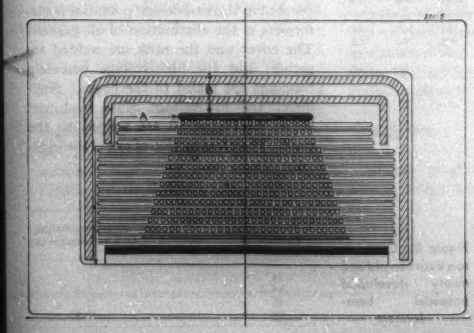


Figure 5. Method of insulating the high-voltage winding (for grounded neutral transformer)

Magnetic Circuit

Some of the benefits of such an efficient coil construction would be lost without a companion magnetic circuit of equal efficiency. The wound-core type of construction,[3] so successfully used in distribution transformers, has been adopted in the new type of potential transformers. The magnetic circuit is formed from magnetic strip material, spirally wound flatwise. The core closely embraces the

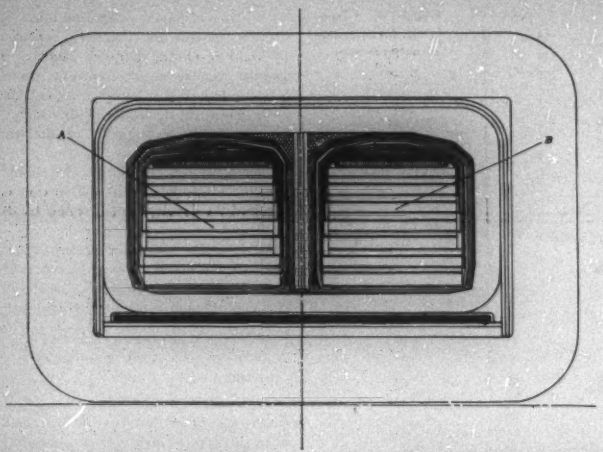


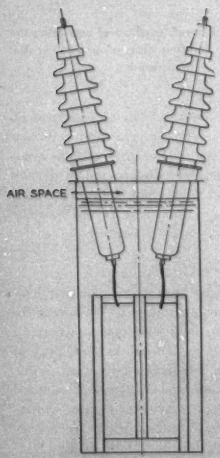
Figure 7. Improved method of insulating the high-voltage winding (transformer for operation between lines)

high- and low-voltage coils so that the coil structure substantially fills the window of the core, providing a high space factor which reduces its volume and weight.

Bushing Design

In the conventional type of high-voltage potential transformers (Figure 8a) which are provided with liquid-filled bushings, there is not connection between the liquid in the terminals and that in the tank. To provide for the expansion of the main liquid, it is necessary to leave an air space under the cover. This air chamber is responsible for the long ground sleeve of the bushings since the ends of these sleeves must always be under oil. Such transformers are necessarily tall and bulky.

If the joint between the tank and the cover is made liquid tight, it is possible to suppress the lower portion of the bushings. Evidently, the expansion chamber of Figure 8a, in the latter case, may be transferred to the top of the bushings. The size of the latter expansion chamber, of course, would be too large if applied to a transformer of the conventional type containing a large amount of liquid. In the new transformers, the amount of liquid is only a small fraction of that used in the conventional design, and therefore it has been found practical to enlarge the top of the porcelain and to use it for the expansion of the liquid. Such a construction is illustrated in Figure 9. In the new design the terminals are made an integral part of the high-voltage coils and are extended inside the porcelain shells.



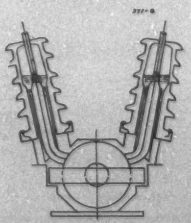


Figure 8. Comparison between old and newly developed potential transformers

Table I

	Relative (Per Cent) Values			
	34,500/115 Volts		69,000/115 Volts	
	Old	New	Old	New
Over-all height	100	51	100	51
Width of base	100	100	100	108
Net weight	100	41	100	42
Liquid volume	100	13	100	16

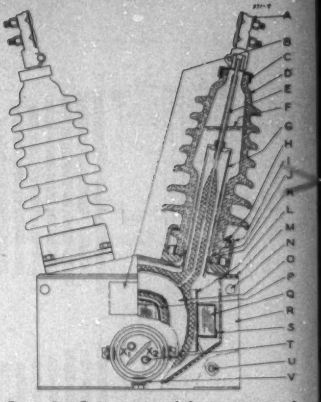


Figure 9. Cross section of the new potential transformer

(a). High - voltage clamp-type terminal
(b). Name plate
(c). Seal
(d). Porcelain bushing
(e). High - voltage lead
(f). Liquid level
(g). Insulating tube
(h). Cushion
(i). Mechanical clamping ring
(j). Insulating collar
(k). Seal
(l). Insulating shield
(m). Welded joint
(n). Lifting hole
(o). High-voltage coil
(p). Low - voltage coil
(q). Core
(r). Tank
(s). Core clamp
(t). Low - voltage terminals
(u). Ground terminal
(v). Low - voltage outlet; remove pipe plug for one-inch conduit

Gasketless Construction

Another notable improvement incorporated in the new design potential transformers is the elimination of all gaskets. The cover and the tank are welded together, and the high-voltage porcelain bushings are sealed to the cover. Similarly, the low-voltage glass bushings[4] shown in Figure 10 are welded to the rank. The cross section of one of the high-

Table II

Voltage Rating (Kilovolts)	Maximum Rating (Kilovolt-Amperes)
24	2
34.5	2.5
46	3
69	3.5

Figure 10. View of low-voltage glass bushing

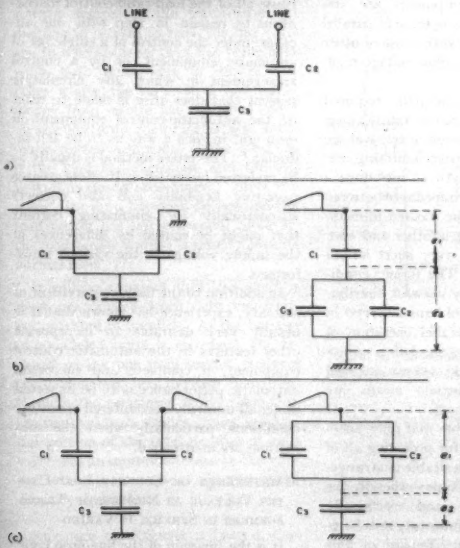


Figure 11. Equivalent circuit of transformer shown in Figure 4 subjected to impulse voltages

voltage bushings is shown in Figure 9. It should be noted that the functions of the mechanical clamping and the sealing of the bushing are independent from each other, thus relieving the seal of any mechanical stresses.

Use of Noninflammable Liquids

In view of the fact that the amount of insulating liquid required in this design is about one sixth to one eighth of the old (see Table I), these units can be insulated with noninflammable premium insulating liquids with very little extra expense.

Maximum Ratings of the New Transformers

The temperature rise of the new transformers is negligible when the units are operated at their normal rating of 500 volt-amperes secondary burden. The maximum rating, on the basis of 55 degrees centigrade with 30 degrees centigrade ambient is given in Table II.

Conclusion

Recent progress in potential transformer design has been primarily due to the development of a novel method of constructing and insulating the high-voltage winding. This novel winding also can be used advantageously with the wound-core construction and can be hermetically sealed without gaskets.

The new transformers are compact and light with accuracy equal to that of previous design. The compactness of these transformers permits the use of premium non-inflammable insulating liquids at little extra cost. The new transformers require little or no inspection and can be mounted in the bus structure near the high-voltage lines.

Appendix

The equivalent circuit of the coils shown in Figure 4, under Impulse Voltages, may be represented as shown in Figure 11a. There are two conditions to be examined:

(a). Impulse wave reaching one line while the other end is grounded.

(b). Impulse wave reaching simultaneously from both lines.

1. Impulse incoming from one line with the other end grounded. Referring to Figure 11b we have:

$$\frac{e_1}{e_2}=\frac{C_2+C_3}{C_1}$$

$$\frac{e_1}{e_1+e_2}=\frac{C_1+C_3}{2C_1+C_3}=p1=\text{fraction of the total voltage appearing across } C_1 \qquad (1)$$

If we assume (as is usually the case) that $C_3=2C_1$ then from equation 1 $p1=0.75$.

2. Impulse incoming simultaneously from both lines. Referring to Figure 11c we have:

$$\frac{C_1+C_3}{C_3}=\frac{e_2}{e_1} \qquad \frac{C_3}{2C_1+C_3}=\frac{e_1}{e_1+e_2}=p1 \qquad (2)$$

If we assume $C_3=2C_1$, then $p1=0.5$

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A New Control System for Automatic Parallel Operation of Load-Ratio-Control Transformers

S. MINNECI
ASSOCIATE AIEE

S. B. FARNHAM
MEMBER AIEE

Synopsis: The successful parallel operation of transformers equipped with automatic load-ratio control and line-drop compensation requires that stability of operation be insured. In addition, experience has shown that it is frequently highly desirable that other automatic features be included which will contribute toward operating flexibility, and which will permit switching transformers in and out of parallel operation without disturbing the voltage level at the load center or causing an excessive initial circulating current at the instant of paralleling.

This paper discusses the conditions which make these added features desirable, and presents a new control system whereby they all may readily be secured. In this new system, load current and circulating current are made to flow in separate paths in the control circuit, and each produce their effects independently, thereby insuring stable operation and maintaining the desired load-center voltage level. This separation of the load and circulating current, in conjunction with a modification in the closing circuit of the paralleling circuit breaker, also makes possible the avoidance of excessive initial circulating current when the breaker is closed. The simplicity and effectiveness of this arrangement in providing a fully automatic means for meeting all the anticipated operating requirements recommends its use in many applications.

THE economic trend in distribution-system arrangement toward locating individual substations at or near the center of each load area, plus increased attention to improved voltage regulation results in a growing number of relatively small substations.[1,2,3] These are frequently from 1,000 to 5,000 kva in size and are provided with means for automatically regulating the bus voltage. They are increasingly of the unit-substation type, in which the functions of three-phase voltage transformation, automatic voltage regulation, switching, metering, and protection are included in a co-ordinated and factory-assembled unit.[4,5,6] In such substations the voltage regulation is normally provided by transformers having built-in load-ratio-control mechanisms, capable of changing taps under load, and equipped with line-drop compensators for maintaining the desired voltage at the load center. Their load-ratio-control equipments are frequently called upon to operate in parallel with one another and with those of other substations having similar voltage-regulating equipment.

Parallel operation may be required where the load-ratio-control transformers are located some distance apart, and are joined together by interconnecting circuits of sufficient length to introduce a substantial amount of impedance between them; or they may be located immediately adjacent to one another and connected by circuits of very short length and low impedance. The former condition is typical of utility network distribution systems. The problems involved in securing successful parallel operation of the automatic voltage-regulating equipments in such network systems are well understood, and adequate means are available for solving them.[7]

A generally applicable and fully automatic control scheme for providing all of the features that are desirable in arrangements of the second type—wherein the units are physically and electrically close together—has, however, not heretofore been available. Typical of this class of application are those cases where rapidly growing local loads have necessitated the paralleling of load-ratio-control transformers in the same substation, or where two or more unit substations are installed side by side and interconnected by circuits of only a few feet in length. A similar condition exists in the case of all double-ended unit substations, in which two load-ratio-control transformers are made integral with a common switchgear section, and thereby connect directly to the same load bus.

The new control system presented here is particularly adapted to applications of this type, but the advantages which it offers may also be realized where the substations or load-ratio-control transformers are some distance apart, provided only that the distance is not beyond the feasible length of interconnecting control circuits. It permits the paralleling of any desired number of units, and yet retains full freedom for independent, nonparallel operation when required.

Operating Requirements

When two or more automatic load-ratio-control transformers with line-drop compensation are operated in parallel, the primary requirement of their automatic-control equipment is that it insure stability of operation.[8] Stability can be achieved automatically either by electrical or mechanical interconnections which cause all of the load-ratio-control mechanisms to remain in step with one another under the control of a single set of automatic equipment, or by a control arrangement in which any circulating current that does arise is made to react on the automatic-control equipment in each unit in such a way as to be self-reducing.[9] This latter method is usually to be preferred inasmuch as it offers greater operating flexibility and also corrects automatically for circulating current that might be caused by differences in the supply voltage to the various transformers.

In addition to the basic requirement of stability, experience has shown that it is usually very desirable to incorporate other features in the automatic control equipment, if complete and successful automatic performance is to be expected under all normally encountered operating conditions, particularly where the substations are unattended.

Maintenance of Correct Load-Center Voltage as Number of Transformers in Service Is Varied

It is the function of the line-drop compensators to indicate to the automatic regulating equipments the amount by which the bus voltage must be altered in order to maintain the load-center voltage at the desired level. This requires that the compensators receive a true indication of the magnitude of the load current. When the number of paralleled transformers is varied, as for example by removing one or more from service during periods of light load, special provision is necessary if the correct load-center volt-

Paper 43-64, recommended by the AIEE committees on electric machinery and automatic stations for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8-9, 1943. Manuscript submitted November 9, 1942; made available for printing March 2, 1943.

S. Minneci and S. B. Farnham are both with the General Electric Company, Mr. Minneci is electrical engineer in the power transformer division at Pittsfield, Mass., and Mr. Farnham is in the central station engineering department at Schenectady, N. Y.

age level is to be preserved without requiring the attention of an operator. The need for such provision may be illustrated by the case of two load-ratio-control transformers operating in parallel and sharing a common remote load, as illustrated by the single-line diagram of Figure 1. With their line-drop compensators set to hold the desired load-center voltage, assume that one of the transformers is removed from service. The load current which was passing through it is thereby diverted through the other. This additional current reacts on the line-drop compensator and automatic-control devices of the transformer remaining in service to raise the bus voltage to a higher level than was being held while both units were in service. In other words, the removal of one transformer from service has the same effect on the line-drop compensator and automatic-control equipment of the other, as if the load had increased, and the bus voltage is raised accordingly. Since the actual line drop between the bus and the load center has not increased, however, the load-center voltage is raised above its normal level.

It will be apparent that this effect is most pronounced when only two units are operated in parallel. As the number of paralleled units is increased, the removal of any one from service produces proportionately less increase in current through the remaining units. However, the removal from service of any substantial portion of the total number of units will cause an appreciable rise in the voltage level; in any case, corrective measures are desirable.

Avoidance of Excessive Initial Circulating Current at the Instant of Paralleling

Unless means are included for bringing the load-ratio-control mechanism of an idle transformer to a position approximating the existing bus voltage level, there may be an excessive initial circulating current when the paralleling circuit breaker is closed. The magnitude of the initial circulating current is a function of the impedance in the loop circuit comprising the load-ratio-control transformers and the interconnecting circuits on both the high-voltage and low-voltage sides, and also of the voltage introduced in the loop by the difference in position of the voltage-regulating mechanisms. In the usual case, the predominant impedance is that of the transformers themselves. The high-voltage and the low-voltage interconnections usually add little impedance, particularly in the case of double-ended unit substations, where the transformers connect directly to a common load bus, or in the case of single-transformer unit substations joined in parallel through short interconnecting circuits. The units are sometimes connected to a common high-voltage circuit, although if each is supplied over a separate circuit, the total loop impedance is usually not increased materially, as the impedance of the high-voltage lines when reduced to a per-unit basis, is generally relatively small.

The maximum circulating current, of course, occurs when a unit whose voltage-regulating mechanism is at one extreme end of its range is paralleled with others whose mechanisms are at the opposite end. It is evident from this that the possibility of trouble arising from initial circulating current becomes greater as the range of the voltage-regulating equipment is increased. As an indication of the order of magnitude of the circulating current, consider as a typical case the two transformers illustrated in Figure 1. If each has a 20 per cent range of load-ratio control, they can introduce a maximum voltage of 20 per cent in the loop circuit when one is at the full raise position and the other at the full lower position. Then, assuming that each has an impedance of six per cent, and that the impedance of the interconnecting circuits is negligible, the maximum circulating current is 20/12, or 1.67 times normal full load current of one unit. This circulating current is essentially a zero power-factor current, and adds to the load current at an angle approaching 90 degrees.

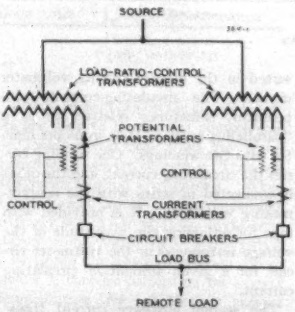

Figure 1. One-line diagram of three-phase load-ratio-control transformers connected in parallel

Automatic-control equipment energized from one phase of each transformer circuit

While excessive initial circulating current can be avoided if the voltage-regulating mechanisms are brought to the same voltage position manually, experience has shown that system operators are usually unwilling to accept this arrangement; and where remote operation or supervisory control over the paralleling circuit breaker is involved, the means for avoiding excessive initial circulating current must be fully automatic almost invariably.

In the new control system recently developed and described in this paper, great flexibility in operation is obtained by incorporating features that will:

(*a*). Insure stable operation during parallel operation.

(*b*). Maintain the correct load-center voltage as the number of transformers in service is varied.

(*c*). Avoid excessive initial circulating current at the instant of paralleling.

(*d*). Permit independent, nonparallel operation when desired.

The various voltages and currents referred to, unless otherwise specified, are those which appear in the secondary windings of potential and current transformers and which are measures of the true values in the power circuit.

The Control Equipment

Each automatic load-ratio-control transformer possesses and is controlled by its own complete set of control devices, including a contact-making voltmeter, line-drop compensator, potential transformer, and current transformer, permitting it, therefore, to operate as an individual unit.

For the purpose of reducing circulating current during parallel operation, each unit is provided with a circulating current compensator and an auxiliary current transformer. In addition, in order to maintain the correct load-center voltage level as the number of units operating in parallel is varied, and to permit the avoidance of an excessive initial circulating current, a second auxiliary current transformer is provided with each unit. Since these two auxiliary current transformers and the circulating current compensator operate in the secondary circuit of the main current transformer, they are physically so small that they may be mounted usually on the control panel. Only five external control wires are required for the interconnections between the units, regardless of the number of load-ratio-control transformers that are to operate in parallel.

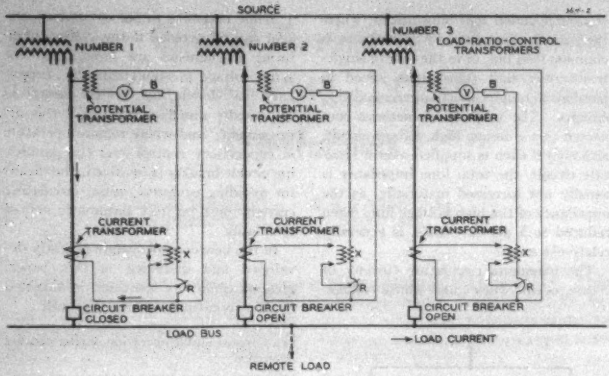

Figure 2. Control arrangement suitable only for individual operation

Principle of Operation

The connections of the control circuits between the several paralleled units, in conjunction with the appropriate connections of the circulating-current compensators and auxiliary current transformers in each unit are such that:

(*a*). Circulating current between transformers does not result in corresponding current in the line-drop compensators. This prevents the line-drop compensation from being influenced by circulating current. The line-drop compensators, therefore, respond only to load current.

(*b*). The load current in each line-drop compensator is always proportional to its transformer's share of the total load current, regardless of whether or not that particular transformer is in service. To accomplish this, the line-drop compensators on all units—whether in service or idle—are kept energized, and equal amounts of the load current flow through all of the compensators at all times.

In the case of transformers of unlike kilovolt-ampere ratings operating in parallel, the currents in the line-drop compensators will be equalized when the load current is divided among the transformers in proportion to their kilovolt-ampere ratings.

Functions of the Circulating-Current Compensator and Auxiliary Current Transformers

One auxiliary current transformer functions to separate the load current from the circulating current. The circulating current thus segregated is, by appropriate connections, forced through the circulating-current compensators of all units in service. A reactive voltage proportional to the circulating current is thereby inserted in the contact-making voltmeter circuit. The circulating-current compensator, sometimes referred to as a "paralleling reactor" is an iron-core reactor with two windings. One winding carries the circulating current, and the other is connected in series with the contact-making voltmeter. It is provided with taps for adjusting the magnitude of the voltage introduced in the voltmeter circuit for a given amount of circulating current.

The second auxiliary current transformer forces an equal division of load current through the line-drop compensators of all the units, regardless of whether they are in service or idle.

Operation of the Control Circuit

To facilitate an understanding of the manner of operation of the control system in which the foregoing features are incorporated, the relatively simple control arrangement for automatic operation of individual units is first considered. Figure 2 is a one-line diagram representing several three-phase load-ratio-control transformers, each with its own set of control equipment. The control circuits are separated from one another, and will be recognized as the arrangement normally used for independent, nonparallel operation, wherein each contact-making voltmeter and line-drop compensator is energized by its own potential and current transformer. With this arrangement, however, only one unit at a time may be connected to the load bus because, if one or more units are added in parallel the presence of any circulating current in the line-drop compensators will cause a further increase in the voltage delivered to the bus by the transformer whose voltage is already high, and a decrease in the voltage of the transformer whose voltage is already low. This results in unstable operation, with one unit going to the maximum raise position and the other going to the maximum lower position, thereby increasing the circulating current

Circulating-Current Compensation

The circulating current, however, can for all practical purpose, be eliminated

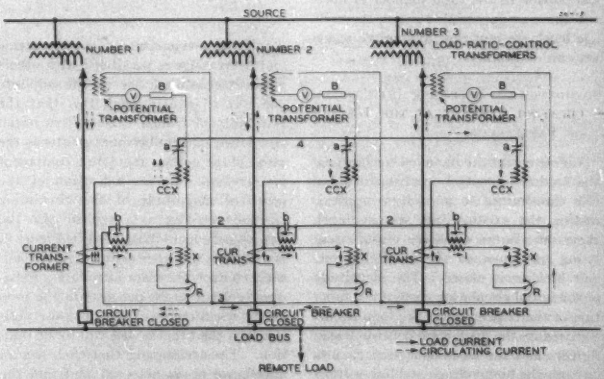

Figure 3. Control arrangement in which load current and circulating current are segregated

The load current indicated by solid arrows flows through line-drop compensators *R* and *X*, while the circulating current indicated by broken arrows flows through circulating-current compensators *CCX*

by inserting in the control circuit of Figure 3 the auxiliary current transformers 1, which separate the load current from the circulating current, and the circulating-current compensator *CCX*. In this figure the three transformers are shown connected in parallel to the load

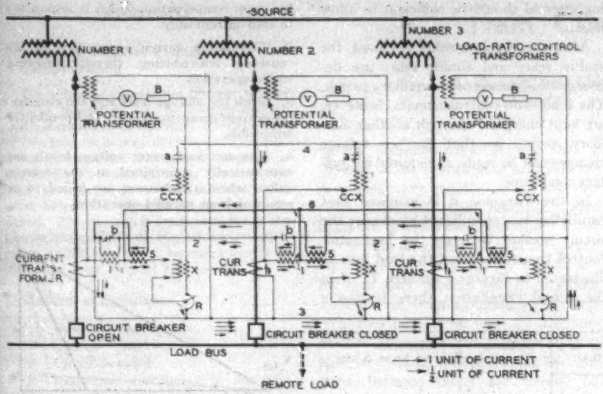

Figure 4. Control arrangement showing the addition of auxiliary current transformers 5 for effecting the proper division of load current among the line-drop compensators when transformers are removed from service

bus. Under balanced conditions, load current flows in the main current transformers and line-drop compensators, as well as in the auxiliary current transformers 1 as indicated by the solid arrows. Since these auxiliary current transformers are connected in series with each other through control wires 2 and 3, equal amounts of load current flow through all the line-drop compensators, thereby introducing the proper amount of voltage compensation in the contact-making voltmeter circuits.

Circulating current appearing in the secondary windings of the main current transformers, however, is prevented from flowing in the afore-mentioned loop by the polarity of the connections, but is forced to flow through the circulating-current compensators *CCX* and control circuits 3 and 4 as indicated by the broken arrows. It will be noted in Figure 3 that the flow of circulating current in the power circuits is from transformer number 1 toward the load bus, returning through transformers numbers 2 and 3. Accordingly, the current in *CCX* for transformer number 1 is in the direction to lower its output voltage, while in the *CCX* elements of transformers numbers 2 and 3 it is in the opposite direction and tends to raise the output voltage. The net effect is the reduction of the circulating current.

The vector relationship of the circulating-current compensation with respect to the voltage applied to the contact-making voltmeter is shown in Figure 6.

Auxiliary switches on the circuit breakers are used to change the control connections automatically when any transformer is removed from service. These are designated as *a* and *b* in Figure 3. When a transformer circuit breaker is opened, auxiliary switch *a* isolates the circulating-current compensator *CCX*, while switch *b* by-passes the auxiliary current transformer 1, thereby permitting the correct compensation for circulating current among the transformers remaining in parallel operation.

If for any reason the controls are prevented from correcting for circulating current, an overcurrent lockout relay (not shown in Figure 3) sometimes is provided to stop operation of the load-ratio-control motor before the current reaches an unsafe value. The relay operating coil is usually connected in series with the *CCX* element where it is responsive to circulating current only, and is, therefore, free from the influence of load current. When the power circuit breakers are equipped with current directional relays for other reasons, as is the normal practice in the case of unit substation, the lockout relay may be omitted. In these cases, the breaker is tripped automatically when the circulating current reaches the value corresponding to the relay setting.[10] The circulating current is thereby removed entirely rather than merely prevented from increasing further.

Equalization of Current in the Line-Drop Compensators

To permit varying the number of transformers in service without affecting the line-drop compensation, a previously mentioned second auxiliary current transformer 5 is added to each equipment, as shown in Figure 4. The manner in which this causes an equal division of load current among all the line-drop compensators will be apparent from the circuit of Figure 4, wherein transformer number 1 is removed from service as indicated by the open position of its circuit breaker.

If it be assumed that three units of current represents the total load current supplied to the load bus by transformers numbers 2 and 3, then each carries $1^1/_2$ units of current. It is apparent that if $1^1/_2$ units of current are allowed to flow through their line-drop compensators, these transformers will raise the bus voltage to a higher level than was being held before the breaker of number 1 transformer was opened, since previously only one unit of current flowed in each compensator. The presence of the auxiliary current transformers 5 however, permits only one unit of current to flow in each of these line-drop compensators, while the excess half units are forced to flow in control wire 6, and their sum—one unit—flows through the line-drop compensator of the idle transformer number 1. The line-drop compensation of all the transformers, therefore, remains at exactly the same value at all times, thereby maintaining the correct bus and load-center voltage levels regardless of the number of transformers in service.

Although in the figures used for illustration, only three transformer units are shown, the complete symmetry of the arrangements makes it apparent that this scheme is applicable to any number. If there are N transformers, X of which are operating in parallel, and if unit current flows in each when $X = N$, then the division of load current among the paralleled transformers will be in proposition to N/X. Only unit current, however, is allowed by the auxiliary current transformers 5 to flow in each of their line-drop compensators, and the excess, which is equal to $(N/X)-1$ or $(N-X)/X$ for each transformer, is diverted to the $N-X$ idle transformers. This results in a total current proportional to $[(N-X)/X](X)$ being divided among $N-X$ idle transformers with the result that each idle transformer also has unit current in its line-drop compensator.

Circuit-Breaker Closing Circuit

To avoid an excessive initial circulating current at the instant of paralleling, advantage is taken of the fact that the correct share of load current is automatically maintained in the line-drop compensators of the idle as well as the active transformers. This makes possible the automatic

equalization of the output voltage with the existing bus voltage, so that when operating conditions require, any idle transformer may again be connected to the bus, with the assurance that its voltage will be of the correct value to permit paralleling without causing a large initial circulating current. A slight phase displacement will exist between voltages as a result of the impedance drop in the loaded transformers, but in the usual case this should not be objectionable.

Figure 5 is a partial elementary diagram showing the salient features of a circuit-breaker closing circuit which permits the automatic voltage equalization

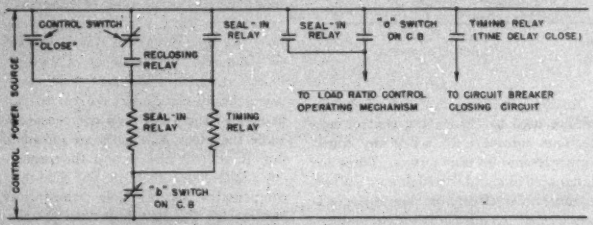

Figure 5. Partial elementary diagram of control circuit for permitting equalization of voltages before closing the circuit breaker

to take place before allowing the breaker to close. In this circuit, the only devices required in addition to those normally employed are a timing relay and an auxiliary seal-in relay. The manner of operation may be seen readily by reference to Figure 5. When the control switch is turned to closed, or when the reclosing relay (if present) operates, the seal-in relay is picked up and sealed. Immediately the load-ratio-control motor circuit is energized and the timing relay is started. This relay has a time interval which is sufficient to permit the load-ratio-control mechanism to reach the position corresponding to the existing bus voltage. A true indication of the bus voltage, as has been shown, is given to the contact making voltmeter of the idle unit by the potential transformer connected to its own output circuit, and its line-drop compensator. At the expiration of the timing interval, the circuit breaker closing mechanism is energized, and the breaker closes. While it is probable that in most cases the idle load-ratio-control mechanism will have assumed the correct voltage position before the interval elapses, there is the possibility that it may occasionally have to traverse its entire range before the correct position is reached, and the timing interval should be sufficient to allow this.

After the circuit breaker is closed, the seal-in relay and timing relay are de-energized by means of an auxiliary switch. The load-ratio-control circuits, however, are kept energized through another auxiliary switch so that further voltage changes can be made as required by system conditions.

In the foregoing it is assumed that paralleling is accomplished by closing the circuit breaker between the load-ratio-control transformer and the load bus, as illustrated in Figures 1 through 4. If in the actual installation there is also a switch or circuit breaker between the transformer and the source, this must be closed first in order that the automatic voltage equalization may occur.

Individual Operation

Since each load-ratio-control transformer is provided with a complete set of automatic-control equipment, any of the transformers shown in Figure 4 may be operated independently. It is necessary only to open control wires 4 and 6 and to by-pass the auxiliary current transformers 1 and 5, thereby reducing the interconnected control arrangement of Figure 4 to the simple isolated arrangement of Figure 2. For this purpose a control switch (not shown) may be used, or if the change from parallel to individual operation is to be made only very infrequently, the necessary changes in the control-circuit connections may be made directly at the terminal boards of the control equipment.

Summary

This new control system provides a means whereby all of the features may be secured which appear desirable in applications requiring the fully automatic parallel operation of load-ratio-control transformers. Its outstanding characteristics are these:

1. Accurately regulated voltage is maintained at the remote load center through line-drop compensation which is responsive to load current only.

2. Circulating current—regardless of its cause—is self-reducing, thereby insuring stable operation.

3. Both the voltage level and the circulating-current compensation are independently adjustable.

4. Bus and load-center voltage levels are automatically maintained at the correct values when transformers are added to or removed from parallel operation.

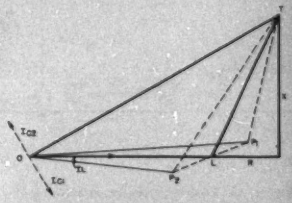

Figure 6. Vector diagram illustrating the corrective voltages impressed on the contact-making voltmeters as a result of circulating current

O-T—Voltage at transformer load bus

O-L—Voltage at remote load center and at each contact-making voltmeter for normal conditions. (No circulating current)

I_L—Load current, 100 per cent power factor

Ic_1—Circulating current through unit 1: lags O-T by an angle approaching 90 degrees

Ic_2—Circulating current through unit 2: leads O-T by an angle approaching 90 degrees

O-P_1—Voltage at contact-making voltmeter on unit 1 when circulating current exists

O-P_2—Voltage at contact-making voltmeter on unit 2 when circulating current exists

R-X—Resistance and reactance voltage components in line-drop compensator

T-L—Total line-drop compensation for normal conditions

L-P_1, L-P_2—Voltage compensation resulting from circulating current

T-P_1—Total impedance drop in series with contact-making voltmeter on unit 1

T-P_2—Total impedance drop in series with contact-making voltmeter on unit 2

5. In order to avoid the occurrence of a large initial circulating current, the output voltage of any idle transformer is automatically equalized with the existing bus voltage before permitting the closing of the paralleling circuit breaker.

6. Any number of load-ratio-control transformers may be operated in parallel, and new transformers may be added without requiring modification of the control equipment on those already in service.

7. Operating flexibility is inherent in this "unit" arrangement which permits either parallel or individual operation.

Appendix

Circulating-Current Voltage Compensation

The effect of circulating current on the voltage impressed on the contact-making voltmeters is shown in Figure 6 for the case of two load-ratio-control transformers operating in parallel. The vector diagram is drawn for the case of unity power-factor load current, and shows the conditions which exist before the circulating current is reduced. No attempt is made to indicate the precise magnitudes of the various components as the diagram is intended merely to illustrate their general relationship.

Definition of Symbols

PT—Potential transformer.
CT—Current transformer.
CB—Circuit breaker.
R—Resistance component in line-drop compensator.
X—Reactance component in line-drop compensator.
V—Contact-making voltmeter.
B—Ballast for contact-making voltmeter.
CCX—Circulating-current compensator.
a—Auxiliary switch on circuit breaker. Closed when circuit breaker is closed.
b—Auxiliary switch on circuit breaker Closed when circuit breaker is open.
$\geq$—Contacts closed.
$=$—Contacts open.

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Train Communication

L. O. GRONDAHL
MEMBER AIEE

P. N. BOSSART
NONMEMBER AIEE

THE communication system that is used in the operation of railroads has developed very rapidly in the last few years. The most recent addition is what is known as train communication, which is a system of communication for operating purposes between railway vehicles and between such vehicles and fixed points. To illustrate, train communication equipment may be used for two-way telephone or code communication between the two ends of a train, between trains and stations, between trains and towers, between two parts of a train that are separated for work or otherwise, between two different trains whether they are on the same or on adjacent tracks, and between the conductor and locomotives in a receiving or in a classification yard. Following are illustrations of the uses to which such equipment may be put:

A. Communication Between Vehicles in the Same Train. This is most important in long freight trains in which it is very difficult to signal between members of the crew. There are many possible applications:

1. The conductor may call for an air-brake test before starting the train and may report to the engineer on the progress of the test, thus decreasing the amount of time required.

2. The conductor can notify the engineman that everyone is on board.

3. He can request the engineman to increase or decrease speed as desired or required.

4. The crews at the two ends of the train can compare train orders received while in motion.

5. Information in regard to change in work to be done at work points can be exchanged.

6. The conductor can give information enabling the engineman to spot the caboose at any desired point, for instance when it is necessary to clear road crossings or switches.

7. When in motion the conductor can report to the engineman dragging brakes, hot boxes, or any other condition that makes it necessary to stop the train, and arrange for the best time and place to stop.

8. The apparatus may be used to obtain the proper co-operation between the hauling and the pushing locomotives on a long train where two or more locomotives are co-operating.

9. The locomotive crew can give information to the crew at the rear of the train concerning causes for delay and estimates of the duration of the delay.

10. The conductor can give instructions to the engineman as to procedure under unusual conditions of any kind without having to walk to the front end of the train.

B. Communication Between Trains. When two trains are passing, the crew of one train may notice something that should be corrected on the other train, and with the communication system it is possible to report such conditions, for instance, as the existence of hot boxes or dragging brake rigging or shifting loads.

C. Communication Between Train and Station or Between Train and Tower. Ability to communicate between trains and stations or towers is valuable first of all in that it enables the towerman to transmit messages to a train crew without stopping the train or reducing its speed. It is important also from the standpoint that it enables the train crew to report unusual road conditions to the towermen.

D. Communication in Hump Yards. In train classification the communication system is a very great convenience in that it enables the conductor, who is usually located at the hump of the yard, to communicate with his locomotives at all times and to tell them what to do, which string of cars to move, when to start, how fast to move, and when to stop. This is useful on the classification side of a hump, as well as on the receiving side.

The applications are so many and so important that one can almost say that in common with all communication equipment, as soon as the equipment becomes available, it also becomes indispensable.

Previously Proposed Methods

Several methods of providing train communication have been proposed. Among the first was the suggestion that the air-brake system might be used as a speaking tube. Investigation revealed that the brake air line was an extremely

Paper 43-72, recommended by the AIEE committee on land transportation for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8–9, 1943, and at the AIEE South West District technical meeting, Kansas City, Mo., April 26–30, 1943. Manuscript submitted January 19, 1943; made available for printing March 2, 1943.

L. O. Grondahl is director, research and engineering, and P. N. Bossart is research engineer, both with the Union Switch and Signal Company, Swissvale, Pa.

The material of the paper is the result of the work of a great number of past and present members of the research department of the Union Smith and Signal Company, especially past members Austin M. Cravath and John H. Findlay.

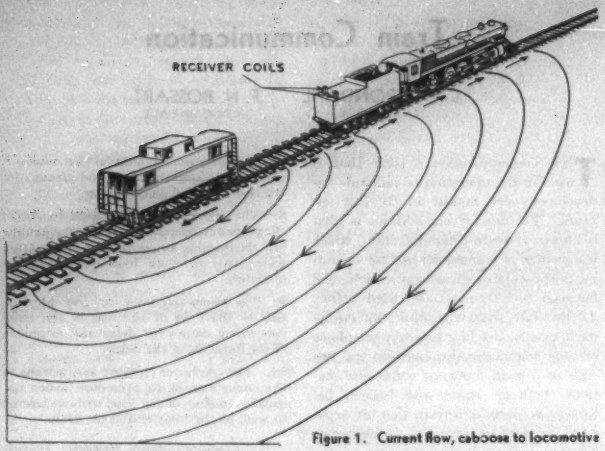


Figure 1. Current flow, caboose to locomotive

efficient low pass filter—so good, in fact, that no frequencies higher than about one cycle per minute could be passed through the brake pipe of a 150-car train. Even this signal could not be transmitted satisfactorily under certain conditions of the brake line, and the extremely low speed of signaling made the system impractical since a single signal would have to combine several pulses and might take five minutes to complete.

Another suggestion required the wiring of all freight cars. The wires were to be connected automatically through the brake line couplers, and there is no doubt that if such a circuit were established, communication over it would be easy. There is the consideration that the wiring of two million freight cars is a large undertaking, and even more important, that both this method and the signaling through the brake pipe have the fundamental limitation that neither can be used if the train is broken. This in itself renders both systems impractical, since communication is often most needed when the train is parted.

Radio has been proposed and tried on many occasions, and it is possible by radio to obtain communication, especially between ends of a moving train. Communication is uncertain in tunnels and fades under steel bridges and similar structures. This condition makes radio unsatisfactory for the purpose. The most important difficulty with radio is that the Federal Communications Commission has not been able to make permanent assignments of wave bands that are suitable. They have to be reserved for the use of services which have no alternative means of communication, such as ships and aircraft.

Commercial Method

The Union Train Communication System, a development of the Union Switch and Signal Company, is in regular commercial use and is being adopted rapidly in railway applications. It is a carrier telephone system transmitting usually the upper side band of a 5,700-cycle carrier and ordinarily feeding the signals conductively into the rails and picking them up inductively from the rails. Figure 1 shows the principle of the system. At the sending vehicle a voltage is produced along both rails in parallel to send out currents through the running rails with the return path through the ground. The signal is picked up at the receiving end by coils in inductive relation to the rails and is amplified and demodulated for reception in the loudspeaker. The apparatus has been developed as a simplex or "press-to-talk" system.

Description of Apparatus

Figure 2 shows the essential parts of a typical equipment. The transmitting circuit is a loop from the insulated truck at one end of the vehicle through the output transformer with tuning condenser to the truck at the other end of the vehicle with the loop completed through the running rails between the wheels of the trucks to which the connections are made. The impedance drop in these rails is the transmitting rail voltage. Speech is transmitted by a telephone-type transmitter and received either over a loud-speaker or over the receiver of a handset.

In Figure 3 two indication lights are shown at the top of the control panel, one showing red when the 32-volt d-c power is on, and the other flickering white with the modulation of the voice to assure the speaker that his message is being transmitted to the rails. The button beneath the lights is used for sending a calling signal which is received as a steady 1,050-cycle note and is sent as a single frequency 1,050 cycles above the carrier. The knob at the bottom of the panel is for the control of the received volume.

In spite of the size of a locomotive, space in the locomotive cab is at a premium, and it is sometimes difficult to find a

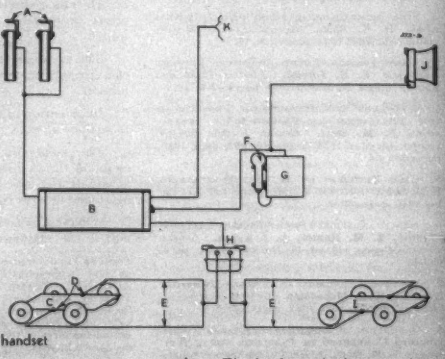


Figure 2. Block diagram of two-way equipment on caboose

A. Receiving coils (located in inductive relation to rails)
B. Equipment box with transmitter-receiver and dynamotor
C. Caboose rear truck (insulated from caboose frame)
D. Connections bolted to truck frame
E. One-inch copper pipe
F. Hand microphone or handset
G. Control panel
H. Output transformer unit
I. Caboose front truck (insulated from caboose frame)
J. Loud-speaker
K. 32 volts direct current from caboose battery: 100 watts receiving; 500 watts sending

place for the speaker and the control box. The speaker may be located against the roof pointing down, and the control panel back of the engineman.

In Figure 4 the transmitter and receiver combined in one frame are at the left, and the 32-volt dynamotor, rated 500 milliamperes 400 volts d-c, combined with switching relay and ripple filters are in the frame at the right.

An optional piece of equipment, sometimes used, is the "signal selector." It includes additional amplification and sharp filtering for the demodulated calling signal which operates a relay. It cannot be operated by short pulses or continuous wide band interference because of a combination of saturation of the tube, time delay in the relays, and narrow band of response. When this equipment is used for calling only, the loud-speaker is disconnected from the amplifier in the stand-by position, and the calling signal operates the bell. When used with signal lights for proceed and stop indications the loud-speaker is disconnected, and a green or proceed light shows as long as the calling signal is being received, but when the calling signal stops, the bell rings, a red light shows, and the loud-speaker is connected ready to receive speech. This provides a proceed indication on the so-called "closed circuit principle."

Figure 6 shows a portable receiving amplifier used on locomotives in hump yards for one-way communication. It weighs about 50 pounds. The circuits are essentially the same as those of the receiver for two-way communication, a 32-volt vibrator furnishing the plate voltage. In addition to the portable box

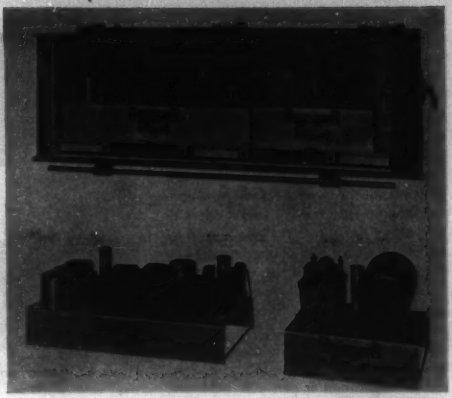


Figure 4. Open equipment box, showing at the top, frames in position in box, and below, frames when removed

shown, engine equipment for one-way communication involves a portable coil for picking up the signal from the rails and a portable loud-speaker and attached volume control for receiving messages in the engine cab. This equipment can be changed from one engine to another in a few minutes.

Equipment Circuits

Figure 7 shows the circuit diagram. The signal is picked up by the receiving coils at top left, amplified, as a single side band through two stages of carrier frequency amplification, and then demodulated by a pair of triodes. Some of the carrier frequency from the oscillator is fed into the demodulator tubes in parallel while the single side band is applied in push-pull. Any undesired high-frequency components are removed by the carrier suppression filter which follows. The output of this filter is applied to the grid of a power tube, and its output feeds the loud-speaker or a handset.

Automatic volume control is provided by the tube at the extreme left where the right half of the twin triode amplifies the demodulated signal taken from the filter input. When full output is reached by the output tube, the peak of this amplified voltage begins to exceed the positive voltage provided from D to ground, and the volume control starts to act by allowing the left half of the tube to rectify and charge the RC circuit connected so as to apply negative bias to the grids of the two carrier frequency amplifiers. The RC circuit provides considerable time delay. This is necessary since, with no carrier, transmitted volume control must be obtained from a time average of the amplitudes of the speech frequencies. Once the volume control begins to act, the output from the last tube stays ap-

Figure 3. Control box with hand microphone and loud-speaker in caboose

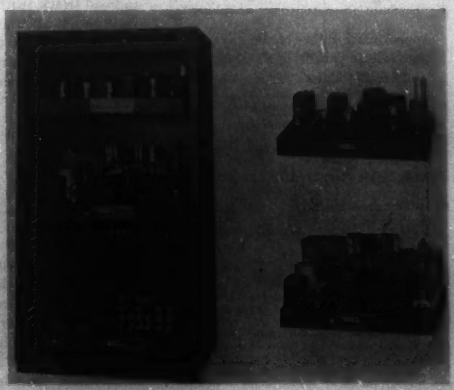


Figure 5. Cabinet for wayside station with receiver on top shelf, transmitter on middle shelf, and power supply at bottom, arranged for 110-volt 60-cycle supply

proximately constant, and the desired level in the loud-speaker or handset is set by a manual potential divider or volume control across the output.

Short high interference peaks are cut off by the peak limiter at an amplitude no higher than required for normal signals to load the output tube. This is a twin triode connected to short-circuit at the filter output the two halves of any amplitude greater than normal, and it operates after the *AVC* adjusts the gain. Normal peaks are set by two sliding contacts on the cathode resistor of the output tube.

In the transmitter the output of a telephone-type microphone is applied to the grids of the modulator stage in push–pull while the carrier energy is applied to the grids in parallel. The resulting modulation, if the circuit is perfectly balanced, does not contain the carrier but does have in it principally the two side bands. Any remaining carrier and the lower side band are removed by the filter which follows, so that practically the tubes which drive the power stage are energized by the upper side band only. The output stage consists of four 6L6 tubes in parallel push–pull and is connected to the sending loop or direct coupling circuit shown in the figure which extends from the engine pilot truck wheels through the rails to the drivers and back through the engine frame.

Transmission Through Track

It is interesting to examine the transmitting characteristics of a railroad track with ground return. The characteristics of any infinite transmission line with distributed constants are determined by four fundamental constants, namely:

R, the series resistance per unit length
X, the series reactance per unit length
G, the shunt conductance per unit length
B, the shunt susceptance per unit length

Approximate values of these quantities for two rails in parallel at 8,000 cycles per second are as follows:

$R = 1.25$ ohms per thousand feet
$X = 12.5$ ohms per thousand feet
$G = 1$ mho per thousand feet (for 3-ohm ballast resistance)*
B is negligible compared to conductance G.

Other symbols used are:

$Z = R + jX$—series impedance per unit length

* Ballast resistance, a common term in railway signaling, is the resistance between the two rails of a unit length of track, 1,000 feet if not otherwise specified. Measurements show the resistance of two rails in parallel to ground is approximately one-third instead of one-fourth the resistance from rail to rail. The reason for this is that some current, with a voltage between rails, flows along the ties and through the ballast without going to ground.

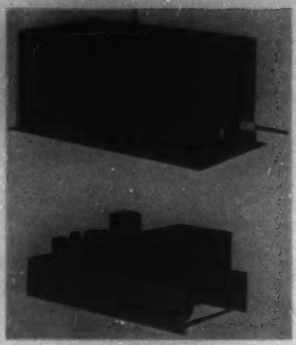


Figure 6. At top, portable receiver for one-way communication. Its chassis is shown removed, below

$Y = G + jB$—shunt admittance per unit length
Z_o = characteristic impedance
$\gamma = \alpha + j\beta$ = transmission constant
α = attenuation constant
β = phase constant

We can apply the formula for the characteristic impedance of a transmission line

$$Z_o = [(R + jX)/(G + jB)]^{1/2}$$

or we can write it as the series impedance and the shunt conductance

$$Z_o = [\underline{Z/\theta}/\underline{G/0}]^{1/2}$$

As we substitute the values chosen we have

$$Z_o = [\underline{12.5/84°}/\underline{1/0°}]^{1/2}$$
$$= \underline{3.5/42°} \text{ ohms}$$

This means that under the conditions assumed, the impedance presented by a railroad track with three ohms ballast resistance is about 3.5 ohms in one direction for an infinite track.

The transmission characteristics are obtained from the equation

$$\gamma = [\underline{Z/\theta} \cdot \underline{G/0}]^{1/2}$$
$$= [\underline{12.5/84°} \cdot \underline{1/0°}]^{1/2}$$
$$= \underline{3.5/42°}$$

or

$$\alpha + j\beta = 2.6 + j2.35$$

Thus, if we start with a current I_o of value 1 at the transmitter, the current will fall to the value $e^{-\alpha x}$ at distance from the transmitter equal to x in thousands of feet, or for the value given, the current will fall to half value in 270 feet. The phase shift is β radians per thousand feet and the wave length, $\lambda = 2\pi/\beta$, or distance for phase to be retarded a complete cycle, is in this case about 2,700 feet.

The equations show that if the conductance, G, is one fourth as great, corresponding to 12 ohms ballast resistance, the characteristic impedance Z_o is twice as great, and the attenuation and phase shift are half as much. In this case,

$Z_o = \underline{7/42°}$ ohms
$\lambda = 5{,}400$ feet
$x = 540$ feet (for $I = I_o/2$)

Range

The current levels involved in train communication are of interest. The current in the rails near the sending vehicle is of the order of $^1/_2$ to 1 ampere. The noise level in a quiet yard track is about 10^{-7} amperes. For communication to be intelligible, it is necessary that the signal should be received at a current level about four times that of the noise level. It follows that the ability to receive a signal with about one-half microampere in the rails represents the maximum usable sensitivity of the amplifier. On an ordinary main-line track of a railroad in a rural region, the noise level is about 10^{-6} amperes. On main-line track through an industrial region, the noise level may be about 10^{-4} amperes. This is measured by noting the noise current through the loud-speaker and then, with noise removed, adjusting and measuring the rail current of a 1,000-cycle modulated upper side band to give the same loud-speaker current. If we take these values and put them into our expression for track attenuation, we find that with 12 ohms ballast resistance, a signal can be received through the track alone, without line wires, at a distance of about $1^1/_2$ miles on main-line track in relatively quiet areas. With paralleling line wires present, speech can be exchanged at 100 miles between a wayside station and a train, and at ten miles or more between moving vehicles.

Choice of Carrier Frequency

If we look at the expression for the attenuation of the track current, we see that it varies directly as the square root of the frequency, assuming that the series impedance of the track Z varies directly as the frequency, and the shunt conductance is independent of frequency, which is very nearly true in the region of interest. Hence, the frequency must not be too high. The frequency must not be too low, because the noise level in the track is much greater for low frequencies. Experiments were made with voice frequen-

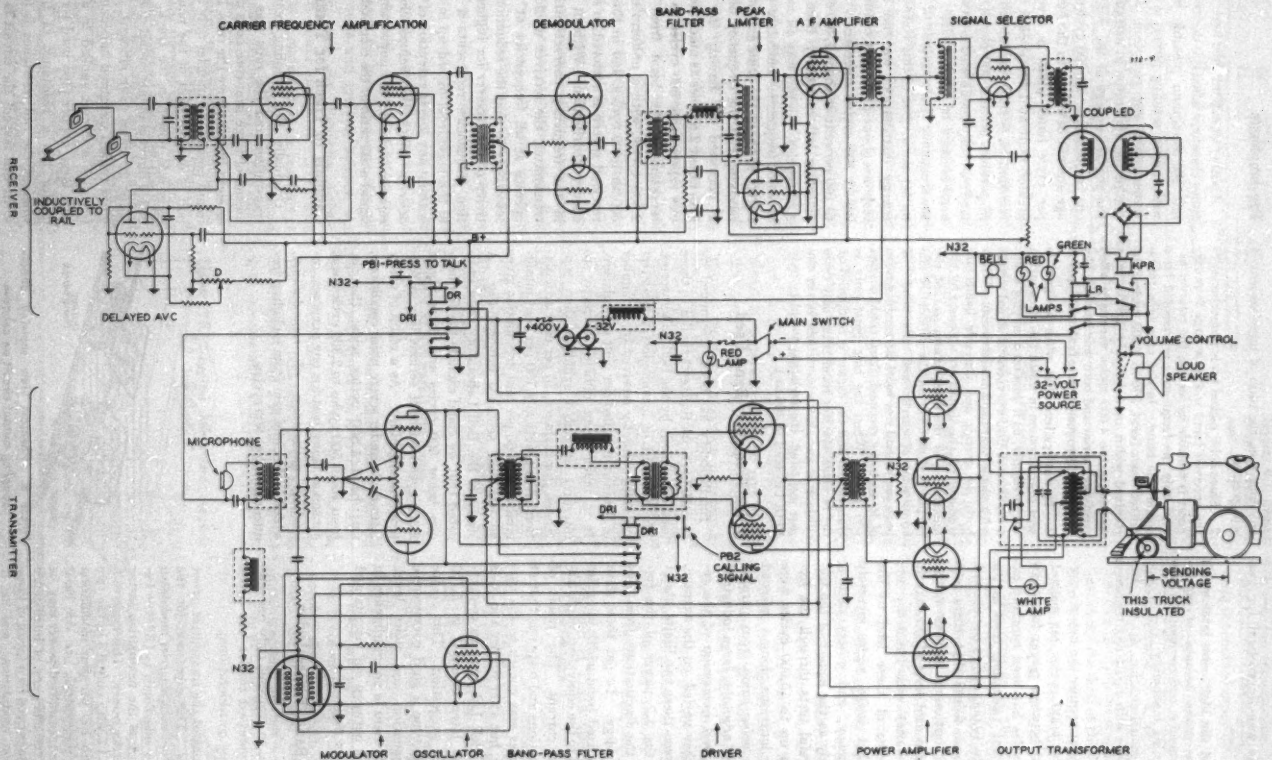


Figure 7. Circuit diagram for two-way train-carried equipment with signal selector

cies, but this was impractical for two reasons:

1. Because of the high noise level which contains large peaks because of power-frequency harmonics and commutator ripples from rotating machinery.

2. Because communication at this frequency interferes with paralleling telephone lines.

These conditions require the use of a frequency above 3,000 cycles per second, and the band between power frequency and 15,000 cycles has been carefully explored, including operating tests in the range 3,000 to 10,000 cycles per second, and it has been found that there is a rather broad optimum in this range. Various theories and tests of the way in which noise varies with frequency are available. Some of these lead to the conclusion that noise varies inversely as the frequency, and others that it varies inversely as the square of the frequency. Careful tests through the frequency range up to 15,000 cycles were made at four locations along a railroad where severe noise came from parallel power lines and adjoining large industrial plants. The best expression of the results is that they varied, on the average, at a rate between these two limits, about inversely as the 1.7 power of the frequency, but the fluctuations from this average were large. To get these data the noise in a fixed band width in cycles was compared to the equivalent single frequency track current. The result of these considerations and tests was that at first 7,000 cycles was chosen as the carrier frequency, but after studies and tests in which the Bell Laboratories co-operated this was later changed to 5,700 cycles at their suggestion. This choice is at the same time a good compromise between attenuation and noise level. In these bands there is no interference in either direction between our circuits and signal circuits or radio.

Single Side-Band Transmission

The decision to transmit only one side band with suppressed carrier was based on the following considerations:

1. The efficiency of the transmitter power unit is greater. The expression for the power transmitted with a carrier modulated to produce two side bands is $(K^2/4)+1+(K^2/4)$, where K is the modulation factor and 1 is the carrier power. This leads to a total power of 1.5 with only 0.5 in the two side bands, with 100 per cent modulation or $K=1$. By transmitting one side band only, all of the transmitted power may be put in it, and the efficiency of intelligence transmitted is improved by a factor of three for 100 per cent modulation; and for K anything less, the ratio of improvement is still greater.

2. Since noise picked up is proportional to the received band width, a large improvement is possible by having the receiver accept only the frequencies represented by a single side band. In the case of a transmitted voice band, 500 to 2,300 cycles, the received width need be only 1,800 cycles instead of the 4,600 cycles necessary when receiving carrier and both side bands. The factor of improvement here is about $2^1/_2$ to 1.

3. It was realized that when a signal is sent over a system in which the attenuation varies rapidly, as it does on a moving train, a much more uniform received signal results with single side-band transmission. When both the carrier and the side bands are transmitted, the signals are obtained by the functioning of the demodulator so that the output is dependent on the product of the amplitudes of carrier and side band. If both carrier and side band change by a ratio of 10 to 1, the received signal could change 100 to 1. When the side band only is transmitted and the carrier is resupplied at the receiver, the side band is the only term subject to variable attenuation, or, in the case just cited, the variation would be only 10 to 1 instead of 100 to 1.

Voice-Frequency Band Used

Intelligibility has been determined by so-called articulation tests similar to those used extensively by the Bell Laboratories. The per cent of meaningless three-letter syllables correctly received by a number of listeners is called per cent articulation. It is much more difficult correctly to interpret unrelated syllables than sentences; for instance, 70 per cent articulation gives practically 100 per cent intelligibility, and 60 per cent articulation gives 99 per cent sentence intelligibility. A study of the Bell Laboratory data indicated that we could exclude the frequencies below 500 cycles and those above 2,300 cycles without serious loss in sentence intelligibility. As a result of many tests made under severe noise conditions, this band 1,800 cycles wide, that is, from about 500 cycles to 2,300 cycles, was chosen as being best for our purposes, including naturalness of reproduction, which is the chief gain from including frequencies below 800 cycles.

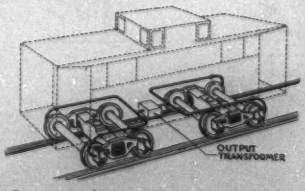


Figure 8. Phantom view showing direct-coupling output circuit on caboose

Pre-emphasis

Another expedient used here, and sometimes elsewhere when it is desired to transmit the maximum possible intelligence with limited sending power, is to set the transmission and reception characteristics of the apparatus in accordance with the average energy of the voice at various frequencies. At 500 cycles the average amount of energy in the human voice per cycle band width is several times greater than at 1,500 cycles; so if the transmitter is fully modulated by voice frequencies around 500 cycles, it will be far from fully modulated by those in the neighborhood of 1,500 cycles. To make the frequency characteristic of the transmitter the inverse of this voice-frequency energy distribution, we can make the response about 40 per cent of full sensitivity at 500 cycles, increase it uniformly to 100 per cent at about 1,400 cycles, and maintain full sensitivity from 1,400 to 2,300 cycles. In this way all components of voice frequencies modulate the transmitter to about the same extent. At the receiving end the frequency distribution is corrected by having the amplifier gain about 2.5 times as much for frequencies representing 500 cycles as for those representing the band from 1,400 to 2,300 cycles, with a uniform drop from 500 to 1,400 cycles, and in this way the received speech is restored to its normal energy distribution. Without a change in the frequency characteristic of the transmitter, the receiver would have to operate at all frequencies at the same sensitivity so that the reduction in sensitivity of the receiver for higher modulation frequencies represents a reduction in the noise level picked up in this band without any loss in reception of the signal desired. With the values chosen this represents about 2 to 1 improvement in the signal noise ratio of the received signal.

Coupling to Track for Transmission

Originally the coupling between the transmitter and the rails was made by means of large iron-core coils carried six or eight inches above the rails, but it was found possible to transfer only about one half of one per cent of the power in the coils into power in the track. The so-called direct coupling circuit of Figure 8 is 15 or 20 times more efficient. Figure 9 gives typical measured impedance values for such a circuit applied to a caboose. The large copper pipe used for the conductor has a resistance of 0.01 ohm, whereas the rail resistance is 0.04 ohm, so in this respect the circuit is fairly ef-

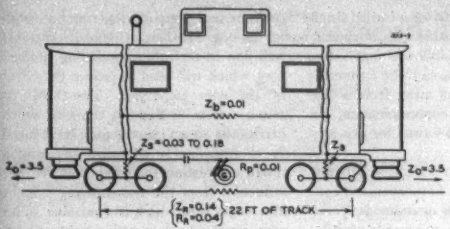


Figure 9. Impedance values for output circuit on caboose

ficient in that about 80 per cent of the power in the output circuit goes into the track itself. However, the coupling between this circuit and the rest of the track is very inefficient. The impedance of the rails from contact to contact on the two ends of the vehicle is 0.14 ohm, and the impedance of the track looking in either direction is about 3.5 ohms for three-ohm ballast. Thus, this circuit, considered as a source of power into the rails beyond the vehicle, is badly mismatched. If we consider the section of the rail under the caboose as the impedance of the source 0.14 ohm, it is feeding into a load of seven ohms, or the impedance ratio is about 50 to 1. Considering as 100 per cent the efficiency of transmission for maximum power transfer when the impedance of the source and the load are equal, then the approximate efficiency for a mismatch is given by the expression $4n/(n+1)^2$ and this, if $n = 50$, gives 7.7 per cent. This expression neglects the phase angles of the impedances, but an accurate calculation including these gives about the same result—8 per cent.[1] It is thus seen that because of the mismatch of impedances we are losing about 92 per cent of the power which we would like to put into the track beyond the vehicle. In case of sending from a wayside station, it is possible to make this factor better than 100 per cent, for we can connect directly between rails and ground, balance out reactance, and, for three-ohm ballast resistance, make our source resistance about 1.30 ohms, which is the real part of the characteristic impedance to ground for the track extending in the two directions in parallel.

Inspection of the output circuit diagram, Figure 9, reveals that there is a shunt path through the vehicle tending to short out the rail which, in the average case shown, might have a value of about 0.2 ohm. This, in parallel with the rail impedance of 0.14 ohm, is not extremely serious and in the case of a light vehicle, such as a caboose, gives fairly satisfactory communication without insulating the trucks. However, the shunt impedance is quite variable, and in the case of the lowest values shown, which are measured values on a steel caboose, an impedance of only 0.07 ohm would be put in shunt with 0.14 ohm in the rail, and a severe lowering of efficiency would result. This situation is very much worse in the case of a locomotive or tender because of the very much greater weight involved. One theory of contact resistance[2] indicates that it varies inversely as the $^1/_3$ power of the orce on the contacts. Experiments indicate the exponent may vary from $^1/_3$ to 1. A caboose weighs about 20 tons, and a tender may weigh 200 tons, so by this theory, taking the contact resistance variation inversely as the square root of the weight, the contact resistances through the body of the tender would be less than one third as great as through the body of the caboose, and these low values in shunt would cause serious impairment of transmission. In the trains now equipped and operating, trucks in both the caboose and locomotive are insulated from the body of the vehicle. The pilot truck of the locomotive is usually chosen for insulation, and the front coupler is also insulated to prevent undesirable shunt paths.

Effect of Transmitting Loop Position

At first it was thought that by having the copper pipe of the loop high, a better circuit would result, principally because by getting the pipe further away from the rail the self-inductance of the rail would be increased, and a given current would give considerably more rail voltage effective for transmission. This is probably true for a wooden caboose, but it has been determined experimentally that it is certainly not true for a steel vehicle which covers almost all the newer design present-day cabooses and tenders. The characteristics of a high loop over the top of the vehicle were compared with a low loop in which the copper pipe is placed just under the floor of the vehicle, and the somewhat surprising result was found that the low loop is more efficient. There are two reasons for this:

1. The presence of the steel body practically eliminates any gain from added height, so that the actual effective height of the high loop is almost the same as that of the low loop.

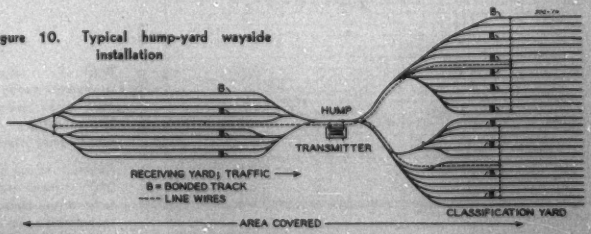
2. Considerably more copper pipe is needed for the high loop, thus increasing copper loss.

The effective height of the high loop was determined by five separate measurements made in different ways. These all led to the same conclusion that the effective height of the high loop was almost exactly the same as the clear air space between it and the rails. In other words, a loop about 14 feet high functioned just the same as one about four feet high, which represents the amount of clear space from ground to the floor of the vehicle, plus the distance from the caboose roof to the high loop.

Relation of Track and Parallel Line Wires

In the system of communication under discussion, the signal is fed into the track and is picked up from the track, usually with assistance in the transmission by mutual induction to and from the paralleling line wires which are nearly always to be found along the right of way. Measurement and calculation show that the induction into the line wire is principally from the track and not from our sending loop. This is not surprising when one takes into account that the length of exposure between the track and the line wires is much greater than that between the sending loop and line wire. It can be demon-

Figure 10. Typical hump-yard wayside installation



strated that the voltage induced in a line wire from a voltage introduced in a track is independent of the ballast resistance of the track, and hence of wet or dry seasons. This can be seen qualitatively by considering that if the ballast resistance is low, larger track currents flow, but they attenuate more rapidly. Analysis shows that the two effects just balance one another. In order to receive the strongest signal, however, experiment shows that it is necessary to orient the coils for maximum coupling with the rails rather than with the line wires.

When sent from a wayside station, the signal is ordinarily applied between a line wire and a track as a ground connection, rather than between tracks, although the latter is done sometimes. With such use of a line wire, conversation between a tower and a moving train 100 miles distant is practical.

Yard Communication

An important application of train communication is found in yards where it is desired to direct the work of several locomotives from one office. Some yards use one-way equipment, office to engine only, while others use two-way equipment which permits the engineman to talk to the office. A typical railroad hump yard is shown in Figure 10. Here communication is desired between the hump and locomotives working any place in the receiving yard and past the entering switches of the classification yard. In order to furnish this communication, line wires are provided as shown dotted in the figure. These line wires may be on pole lines if these are present in suitable location, or clearances permit building new ones. It is generally best not to have these wires immediately adjacent to open-wire telephone pairs unless special transpositions are used, but pole lines carrying power, telegraph, or signal wires may be used. Often a buried single conductor Parkway cable with nonmetallic sheath is used. Lines are supplied so that no point in the area to be covered is more than ten tracks away from a line wire for one-way communication, or more than seven tracks away for two-way communication.

One-way yard communication depends on rail currents which flow because of conductive connection to or induction from the line wire. Hence, to provide positive rail paths, one rail of each third track is bonded so that a locomotive will always have rail current flowing in its own or in the immediately adjacent track, which is near enough for satisfactory inductive pick-up of the signal. For two-way communication, one rail of each track is bonded to provide positive rail paths for the locomotive sending currents. When trains operate on well maintained main-line track, it is not necessary to bond, but bad electrical connections in rail joints are common in yard tracks.

The sending voltage at a yard office or wayside station is connected between the line wire and ground. Any bonded track of considerable length may be used for a ground. At the limits of the area covered, the line wires are grounded to the bonded tracks. Direct connections between line wires and tracks are not necessary, since mutual induction between line and track will supply communication, but the connection line to rail is usually the most convenient way to terminate both line and bonded tracks at the coverage limits.

Approximate calculations can be made of the communication currents in such railroad yards. A primary factor is the mutual induction between a line wire and a track, and this may be determined from published charts.[3]

There are several other effects to be taken into account, one of which is the loss occurring when the signal is fed into one wire in a group of wires running parallel to one another. Opposing currents will flow in the other paralleling conductors, which will tend to reduce the effect of the wire employed. Two-thirds as much current as flows in the wire which carries the signal current may be induced in an immediately adjacent wire, and a rough calculation indicates that the net induction from the transmitting current in a single wire which is a member of an open wire lead can be estimated by dividing the calculated value for a single wire alone by three times the square root of the number of additional paralleling wires. Likewise, the currents induced into any one track are reduced by mutual induction from the currents flowing in adjoining tracks. A study of this effect indicates that current calculated in any one track considered alone must be divided by the square root of the number of tracks between it and the line to approximate the actual current.

In considering transmission in the opposite direction, the effect of interfering tracks is the same; that is, they interfere with transmission from a track to a line in about the same way. However, multiple wires on a pole line are an aid in this case because the currents in each are approximately inphase and they add in effect on a receiving means able to pick up from all the wires equally well. The results obtained with these methods of calculation agree with the results of some field measurements within ±30 per cent.

References

1. Transmission Networks and Wave Filters (book). T. E. Shea. D. Van Nostrand Company, Inc., New York, N. Y. 1929. Page 108.

2. Resistance of Contacts to the Flow of Electric Currents, John C. Simmonds. *The Electrical Times*, September 30, 1937. Page 427.

3. Mutual Impedances of Grounded Circuits, George A. Campbell. *Bell System Technical Journal*, October 1923.

Thermal Rating of Overhead Line Wire

MYRON ZUCKER
MEMBER AIEE

THE major problems in rating overhead wires according to thermal limits are

1. How materials lose their strength.
2. How hot wires become when various currents are passed through them.

Much scattered work has been done on these subjects in the last 20 years, but results have been either inconclusive or, in many cases, contradictory. This discussion brings together data from many sources, adds certain data, and outlines the general problem.

Omitting the obvious discussion of efficiency and voltage drop, let us say that the rating of overhead wires must be such that there shall be no appreciable weakening of the conductor material and clearances at the higher temperatures of operation must be ample. To solve this general problem, we must obtain data on the following specific phase:

I. PERMISSIBLE TEMPERATURES

(*a*). To retain the strength of wire. This depends on time of heating, impurities in the wire, and to a less degree on amount of cold working prior to heating.

(*b*). To protect wire covering from undue deterioration.

(*c*). To preserve reasonable clearances.

II. TEMPERATURE THAT THE WIRE WILL ATTAIN

(*a*). Basic thermal relations expressed as temperature rise versus current, wire size and material, wind at various directions, and sunshine.

(*b*). Weather conditions under which heating will occur, finding reasonable values of wind, temperature, and rain combinations under normal and emergency operation.

Importance of Frequency and Duration of Overload

The total expected duration of heavy loads affects permissible temperatures, acceptable minimum ground clearances, and probable adverse weather combinations. Therefore, any thermal limits must be made with reference to specified frequency and duration of overload.

I. Permissible Temperatures

Ia. Maximum Temperature That Will not Anneal Wire

We will confine our metallurgical study to copper. The cold-worked copper used in overhead lines has its crystals so arranged that overheating will start new crystal growth that weakens the wire. Some X-ray diffraction tests (of which details will follow) indicate that the beginning of recrystallization coincides with a loss of five per cent of the tensile strength of the wire. We therefore adopt this as the allowable loss of strength by annealing. The problem is then to express temperature and time that will produce five per cent loss of tensile strength.

The solution cannot be found directly in the literature, because few of the 37 authorities[1–37] consulted give results in directly usable form. However, by correlating some curves (such as Figure 1) and many isolated points, the field can be roughly covered. Figure 1 is a sample of tests in which many pieces of one wire were heated for various times and then broken in tension after cooling. From these curves, the time-temperature combinations for five per cent decrease in strength can be found. The curves presented by different authorities show considerable variation, but results can be reconciled reasonably well by considering the chemical impurities. Fortunately, in this type of copper only oxygen and silver remain in important quantities.

Figure 2 shows the permissible temperatures for one hour. Some of the points are from curves such as Figure 1, but most are from isolated test runs of $\frac{1}{2}$ to 2 hours. The latter were corrected to one hour by comparison with other investigators' strength-time curves. Some points are from hardness or elongation tests, corrected to equivalent breaking-strength results from interlocking reports. (A loss of one per cent in Vickers, Brinell, and scleroscope hardness corresponds to about five per cent loss of tensile strength, but Rockwell tests lagged about 50 degrees centigrade in showing the change.)

The trends of the points in Figure 2 are indicated by the labeled areas. From these we see that permissible temperatures increase with silver content, with the most minute parts of silver having greatest effect. We also see that oxygen is only important when below 0.02 per cent.

Typical compositions of wire copper are indicated, but the range of individual coppers is great. "Lake" copper, common before 1924 but since then used only on mile-long seamless draws, varies naturally as mined. The amount of silver in electrolytic copper varies with the value of silver. Oxygen-free copper is not commonly used for conductors but shows what can be accomplished by fine chemical controls.

We now turn to curves of temperature versus time (Figure 3). Considering the wide range of conditions represented by these authors, the agreement in trends is good. The shape of these curves, plus some isolated tests, were used therefore to draw a chart for four values of silver (Figure 4), whose intercepts at one hour were selected from Figure 2. From these curves, if silver is known, temperature may be estimated for any time of heating. If silver is unknown, tests may be run at 200 degrees centigrade for periods varying from one-half hour to a day (that is, data obtained as in Figure 1), and time at which the wire loses five per cent of its strength spotted on Figure 4. The nearest curve can then be taken to represent the action of this material. Such tests substitute for chemical analyses.

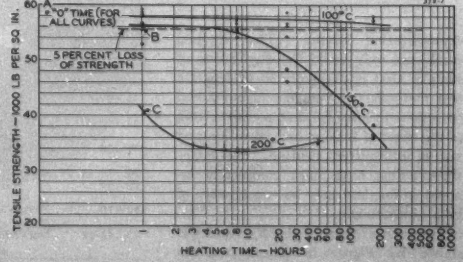


Figure 1. Cold breaking strength in tension versus time of application of several temperatures

For number 6 strands from number 000 copper wire after some years service

Paper 43-73, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE North Eastern District technical meeting, Pittsfield, Mass., April 8–9, 1943. Manuscript submitted February 23, 1943; made available for printing March 19, 1943.

MYRON ZUCKER, on leave from The Detroit Edison Company, is with the Jam Handy Organization, Detroit, Mich.

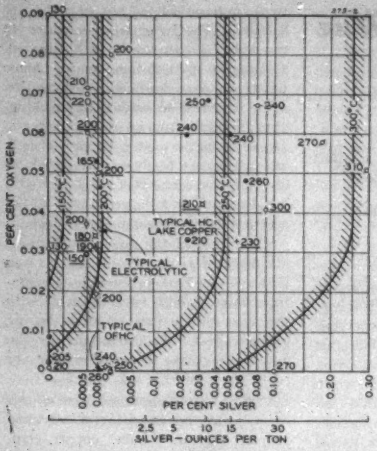


Figure 2. Influence of oxygen and silver on temperatures that will cause five per cent decrease in copper strength if applied one hour

Each symbol represents a different authority

Underlined values are estimated

Metallurgists will note the absence of history of the metal prior to cold-working, and degree of cold working, from this graph. The effects are relatively minor for the strengths, times, and temperatures involved in this problem.

The results are admittedly crude. If the problem continues to be important, we might suggest that outdoor spans be set up, heated as desired, and tested regularly by X-ray diffraction until recrystallization begins. This method would not only avoid the duplication of samples that is necessary in destructive test methods to average out individual variations in material, but permits study of the effect of tension and vibration and also of intermittent heating. The latter three points have been completely ignored so far, and may be conceivably of major importance.

The sensitiveness of the X-ray test is shown by Figure 5. These patterns were made by D. McCutcheon of the Ford Motor Company, at the author's instance. Figure 5*A* shows an unannealed specimen; Figure 5*B* shows a piece heated for an hour at 150 degrees centigrade; and Figure 5*C* shows a piece heated for an hour at 200 degrees centigrade. The black spots in Figure 5*C* are from recrystallization. The specimens when broken in tension (points are shown by *A*, *B*, and *C* on Figure 1) showed 58.3, 56.5, and 40.5 thousand pounds per square inch strengths.

Figure 5*D* is from another strand in the same wire, subjected to the same treatment as Figure 5*C*. Only a moderate number of new crystals appear, and the strength was about 50 thousand pounds per square inch. This strand had more silver than its mates.

To round out the subject of wire strength, we may add that there is no evidence that nicks or burns too small to call for replacement under normal good practice impose any lower limit; tests have shown that modern joints are equal to their proper wires in carrying capacity.

Ib. Wire Covering

The dripping of compound and loss of dielectric may impose limits on the heating of covered wires.[39] No results are yet available that include the time element. Recent tests on *URC* covering indicate that it may safely be taken to 100 degrees centigrade for ten hours.

Ic. Clearances

To operate lines at high temperatures, the increased sag should be computed and the line surveyed to see whether that much loss of clearance can be spared, considering the expected frequency of heavy electric loading. As an example, sags after heavy ice-and-wind loading of a number 000 copper line with 600–800 foot spans is about 2.8 feet more at 210 degrees Fahrenheit than at 120 degrees Fahrenheit and 4.5 feet more at 270 degrees than at 120 degrees.

II. Temperature That the Wire Will Attain

IIa. Wire Heating

The studies of Schurig,[40] Luke,[41] and others,[42–53] have given a reasonably good basis for predicting temperature rise of wires under a limited range of temperature rise and wind speeds. Further tests over wider ranges, and including various wind directions, were made by the Detroit Edison Company last spring, when decisions were required on the rating of certain transmission lines. Figure 6 shows a typical set of data. The curves are self-explanatory.

According to these later tests, when there is no wind the temperature rise depends on the 1.9 power of current (running from 1.8 to 2.0 for different wire sizes). As the temperature rose, the local air current induced by heating increased until at about 150 degrees centigrade rise the vertical air movement

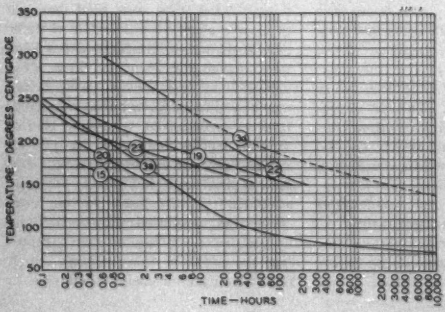


Figure 3. Temperature to begin weakening of copper wire held continuously in oven under no stress

Beginning of weakening shown by one per cent decrease in hardness or five per cent decrease in tensile strength (cold)

Authority	Copper: Initial Strength	Copper: Silver (Per Cent)	Copper: Oxygen (Per Cent)	Test Method
3a	57–59	0.001	0.009	Vickers, tensile
3d	50±	0.0017	0.001	Vickers numbers
15	36	Not stated		Tensile strength
19, 20	51, 55, 57, 59	0.0005 Not stated	0.07	Scleroscope Tensile strength
22	70	0.035–0.069	0.05 0.065	Tensile strength
23	42–62	Not stated	0.066	Tensile strength

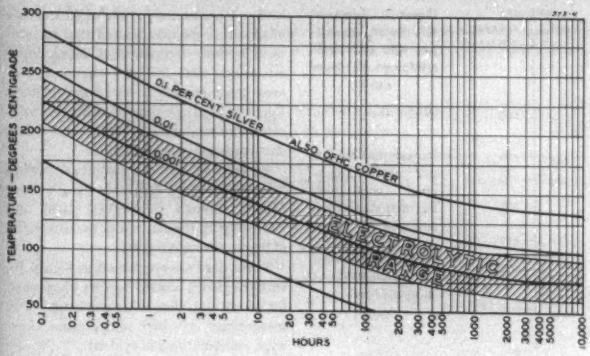


Figure 4. Temperature versus time to reduce strength of copper wire by five per cent

For various silver contents when oxygen is 0.02 per cent or more. The curve for 0.1 per cent silver also may be used for typical oxygen-free high-conductivity copper

was one half mile per hour. This circulation was more effective, per unit speed, in carrying away heat than equal real wind speeds. This accounts for the difference in slope between the no wind and wind curves.

Wind, even at low speeds, was found to decrease temperatures materially. The temperature varies as the 2.3 power of current. The direction of wind is now of prime importance; when parallel to the wire, a 2.4 mile per hour wind permits temperature to rise 205 degrees centigrade compared with 180 degrees for wind at right angles to the wire.

From data available at the time, the nomograms of Figures 7 and 8 were drawn. Some inconsistencies are being checked by further tests, but the charts are believed reasonably accurate.

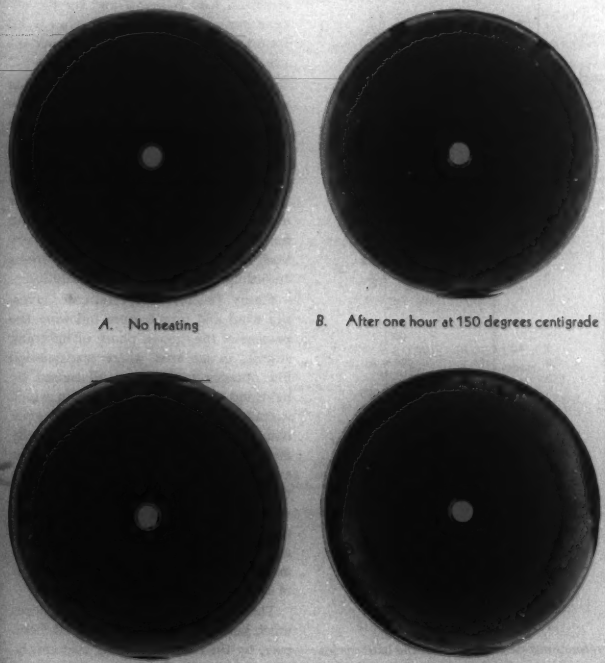
It will be noted that sunshine has had no place on these charts. At the elevated temperatures, the influence is minute. More important, we should note that wind is a more critical factor than is a variation of temperature in the range of ambients ordinarily encountered. For instance, the following combinations will heat number 0000 bare copper wire to 100 degrees centigrade:

Ambient Temperature (Deg C)	Wind Velocity (Miles Per Hour) 0	1	2	5	
10	400	540	570	650	amperes
30	350	480	510	600	amperes

The temperatures listed, change the current about 12 per cent, whereas one mile per hour of wind increases the current about one third over the calm.

IIb. Weather

Weather is really a corollary to part IIa, but it takes so much effort as to deserve separate treatment. Because of the present shortage of copper, we cannot



A. No heating

B. After one hour at 150 degrees centigrade

C. After one hour at 200 degrees centigrade

D. High silver-copper after one hour at 200 degrees centigrade

Figure 5. X-ray diffraction patterns for copper wire

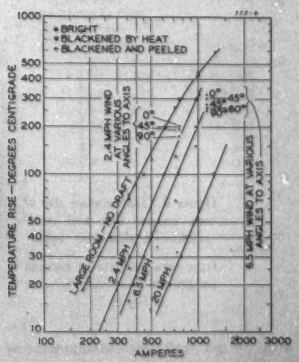


Figure 6. Temperature rise versus current

In number 000 bare stranded copper wire for various wind and surface conditions

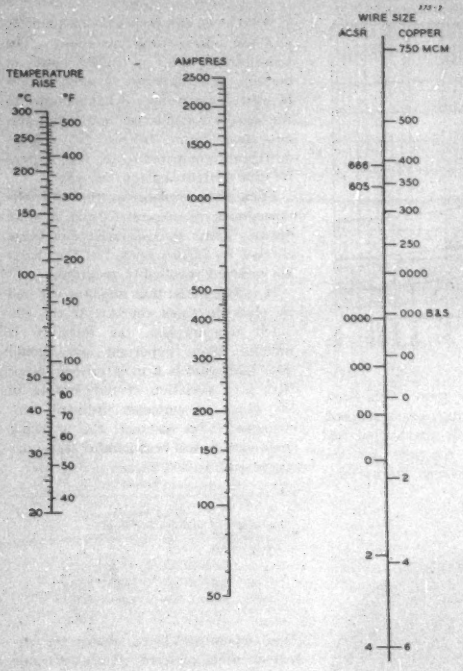


Figure 7. Temperature rise of bare copper wire and steel-reinforced aluminum cable

When there is no wind

Increase current five per cent for blackened conductors. Decrease current five per cent for bright conductor. Increase current 10 per cent for steel-reinforced aluminum cable conductors

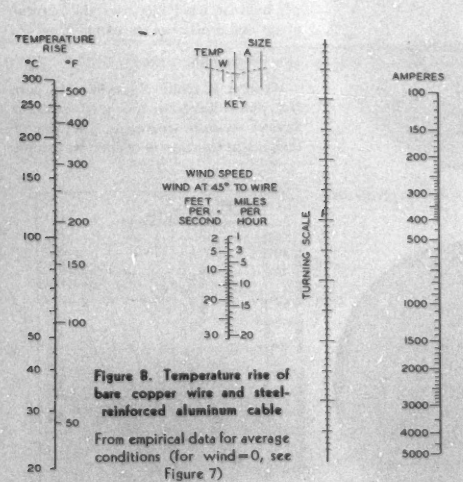


Figure 8. Temperature rise of bare copper wire and steel-reinforced aluminum cable

From empirical data for average conditions (for wind = 0, see Figure 7)

work on the "safe side" assumptions of most adverse weather conditions.

The procedure in finding reasonable combinations of wind and temperature to use in Figures 7 and 8 depends on the refinement desired, and on the load cycles or emergencies being studied. Figures 9, 10, and 11 show one form in which data may be presented for normal rating of a circuit that has continuous daytime load. A preliminary study of the weather observatory records showed that in summer, besides temperatures being highest, winds were lowest. Therefore, records were compiled for summer only. Further scrutiny showed that the coincidence of rain and low winds was so small that rain can be neglected.

Figure 9 shows the distribution of wind and temperature for each month from March through September, 1940 and 1941, during the normal peak-load hours of 8 a.m. through 5 p.m.

These data are condensed in Figure 10, with frequency plotted against wind speed for winds up to five miles per hour. The meagerness of high-temperature low-wind combinations is evident.

Finally, Figure 11, showing frequency of various winds, regardless of temperature, gives a straightforward curve for choosing wind speed after a permissible frequency has been selected. Data are for July and August (which Figure 9 shows to have the worst combinations) for five years, and curves are plotted for both the part of the day when the electrical load is heavy and for the off-peak period. Percentage of calms is 1.5 for on-peak hours, or on the average 6.5 per month.

On this basis, considering the number of hours the heavy load is expected to endure, the permissible operating temperature for the wire may be selected from Figure 4 and corresponding current from Figure 7.

Frequency curves are more important under emergencies, when they give data for comparing the coincidence of heavy loads with various weather conditions according to the theories of probability.

Figure 12 shows a special case: average wind and temperature following the passage of the intense phase of lightning storms, in an area where transmission line outages were almost all caused by lightning. There are no cases in which average wind was less than six miles per hour, and temperatures are generally 80 degrees or cooler. Incidentally, on the average there were four hours of rain in the eight-hour period. With such data, wire rating may be specified for these conditions. This should be checked against the one-hour values, and allowance be made for the proper proportions of outages from other causes.

This type of investigation requires much labor. It is often warranted, however, by the increased rating that can be assigned to a line with reasonable assurance. Incomplete data may be misleading—but still not so much as values chosen by common-sense estimates.

Summary of Conditions in References on Annealing of Copper

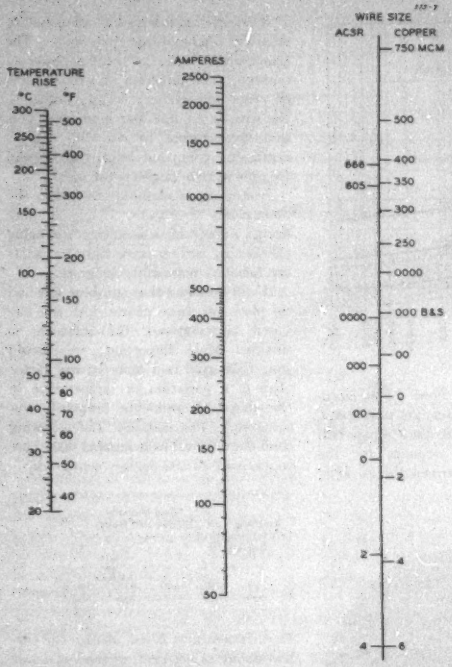
Reference Number	Author	Initial Conditions: Strength (Thousand Pounds Per Square Inch)	Initial Conditions: Per Cent Cold Reduction	Initial Conditions: Strand or Gauge	Type Copper: Per Cent Silver	Type Copper: Per Cent Oxygen	Type Copper: Commercial	Test Conditions: Tension While Heated (Thousand Pounds Per Square Inch)	Test Conditions: Test Method	Test Conditions: Variables: Time (Hours)	Test Conditions: Variables: Temperature (Degrees Centigrade)
1	Wacker	62	71	6	NS	NS		0	T	x	100–200
2	Unknown	52	71		NS	NS		0	T, E	x	250 and 300
3	Voce	60–57		14–6	0.0017	0.001	OFHC	0	T	x	80
		59–57		14–6	0.001	0.019	E				
		59–58		14–6	0.00006	0.030	EC				
		50±	50	0.56 inch	0.0017	0.001	OFHC	0	V	1 and 24	200 and 600
					0.001	0.019	E			x	250
					0	0.030	EC				
4	Beedle	65		6	NS	NS		10	T	48	100–150
5	Zickrick			34	NS	NS				0.05	225–325
6	Bradley	73			NS	NS					25–500
7	Talbot	NS	NS	NS	NS	NS	E	0	J		
8	Price	48	25	NS	NS	Low	E	0	TH*		150–1,000
9	Jares	57		NS	NS	NS	E	0	T	x	180
10	Bassett				See reference 24						
11	Bassett	NS	NS	NS	NS	NS	E				
12	Taylor	Soft		6	NS	NS	NS	5	T	x	
13	Parker	30	0		0.001	0.035	E	High	T	x	200
					0.002	0	OFHC				200
					0.054	0	OFHC and silver				200 and 250
14	Fuller	NS	NS	NS	NS	NS	E	High	T	20	165
		NS	NS	NS	0.03	NS	L		T	140	300
15	Alkins	63	93	0.26 millimeter	NS	NS		NS		x	150–200
16	Pratt	58	62	NS	NS	NS	E		T, E	1	x
		56	62	NS	NS	NS	L				
		58	62	NS	NS	NS	OFHC				
17	Zeerleder	NS	NS	NS	NS	NS	NS	NS	NS	1,000	80
18	H. Moore	60–58		14–19	NS	NS		0	T	x	100
		57	69	Strips	0.0005	0.07	E	0	S(T)	1/3	100–500
		NS	67	Strips	0.1	0	Pure + silver				
		NS	67	Strips	0	0.09	Pure, oxidized				
		53	67	Strips		Pure copper (special)		0	S	1/3	100–500
19	Caesar	NS	67	Strips	0	0.03	Pure, slightly oxidized				
		NS	67	Strips	0.002	0.08	Pure, oxidized plus silver				
		57–51	69–51	Strips	0.0005	0.07	E	0	S	x	150–300
20	Offer	62 before aging / 59 at test		6		Present	E	0	T	x	100–200
21	Wyman	64	58, 85	8	0.024–0.058	0	OFHC + silver	34	E	x	105
		64	58	8	0.024	0	OFHC + silver	26–34	E	x	105
		62	50	8	NS	NS	E	26–34	E	x	105
		62	50	8	NS	NS	E	24	E	x	150
			20 / 37 / 60	Sheets	0.001–0.132	0.05±	L	0	R	1/3	200–400
22	Kinney	70–75	99.8	24	0.001–0.132	0.05±	L	0	T, E	0.033	275, 300, 325
		70–73	97.5	16	0.001–0.32	0.05±	L	0	T	x	150 and 200
23	Pilling	42–62	23–84		NS	0.066	E	0	T	x	100–900
24	Bassett	58	10	Nos. 0.05-inch sheet	0.0005+ / 0.0868	NS	E, L	0	T, E	NS	0–1,000
25	Rolle	59	62	0.5-inch tube	0.0022	0	OFHC	0	T, E	1	190–700
		59–63	62–91		0.002	0	OFHC	0	T, R	1	250–400
26	Webster	56	62–90	6–0	NS	0.0285	E	0	T, E	1	180–800
		59	62–90	6–0	0.0216†	0.033	L				
		57			0.002	0.0	OFHC	0			
27	Angus	NS	33–78	0.28 and 0.31 inch	NS	NS	E	0	B	1	100–600
28	Crard	56	57	2 millimeters	NS	NS	E	0	T	0.5	100–300
29	Bardwell	66		12	NS	0.026–0.07	E	0	T	0.33	100–400
30	Mathewson	51	50	0.065 inch	0.0005	0.071	E	0	T, E	0.67	100–1,000
31	Zickrick	62–69			NS	0–0.028		0	T	0.1	200–400
32	Archbutt										
33	J. L. Gregg										
34	Lorig										
35	Widman	98			0						
					0.24						
36	Hudson	28			0.05	NS	Pure + Silver	0	B	2	300–500
		50			0.08	NS					250–500
37	Johnson	28–59	0–98 / 60	Strip	<0.01	0.05	E	0	T, E, S	1	200–800
					NS	0.089		0	T, E	0.5	200–470

Symbols:
In column "Commercial Type"
P—"Pure"
E—Electrolytic
L—Lake
C—Chilean

OFHC—Oxygen-free high-conductivity
"*NS*" = Not stated
In column "Test Method"
J—Judgment
T—Tension test

E—Elongation
R—Rockwell hardness
B—Brinell hardness
V—Vickers
S—Scleroscope
H—Hardness

In column "Time" an "x" indicates that a time-temperature curve is given
*Apparently tested while hot. Strength lowered at lowest temperature tried.
† High in arsenic and antimony.



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When there is no wind

Increase current five per cent for blackened conductors. Decrease current five per cent for bright conductor. Increase current 10 per cent for steel-reinforced aluminum cable conductors

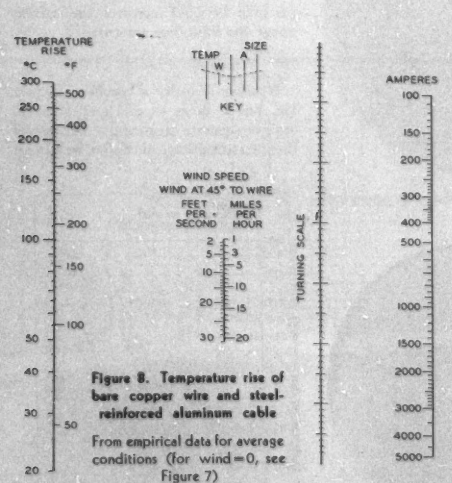

Figure 8. Temperature rise of bare copper wire and steel-reinforced aluminum cable

From empirical data for average conditions (for wind = 0, see Figure 7)

work on the "safe side" assumptions of most adverse weather conditions.

The procedure in finding reasonable combinations of wind and temperature to use in Figures 7 and 8 depends on the refinement desired, and on the load cycles or emergencies being studied. Figures 9, 10, and 11 show one form in which data may be presented for normal rating of a circuit that has continuous daytime load. A preliminary study of the weather observatory records showed that in summer, besides temperatures being highest, winds were lowest. Therefore, records were compiled for summer only. Further scrutiny showed that the coincidence of rain and low winds was so small that rain can be neglected.

Figure 9 shows the distribution of wind and temperature for each month from March through September, 1940 and 1941, during the normal peak-load hours of 8 a.m. through 5 p.m.

These data are condensed in Figure 10, with frequency plotted against wind speed for winds up to five miles per hour. The meagerness of high-temperature low-wind combinations is evident.

Finally, Figure 11, showing frequency of various winds, regardless of temperature, gives a straightforward curve for choosing wind speed after a permissible frequency has been selected. Data are for July and August (which Figure 9 shows to have the worst combinations) for five years, and curves are plotted for both the part of the day when the electrical load is heavy and for the off-peak period. Percentage of calms is 1.5 for on-peak hours, or on the average 6.5 per month.

On this basis, considering the number of hours the heavy load is expected to endure, the permissible operating temperature for the wire may be selected from Figure 4 and corresponding current from Figure 7.

Frequency curves are more important under emergencies, when they give data for comparing the coincidence of heavy loads with various weather conditions according to the theories of probability.

Figure 12 shows a special case: average wind and temperature following the passage of the intense phase of lightning storms, in an area where transmission line outages were almost all caused by lightning. There are no cases in which average wind was less than six miles per hour, and temperatures are generally 80 degrees or cooler. Incidentally, on the average there were four hours of rain in the eight-hour period. With such data, wire rating may be specified for these conditions. This should be checked against the one-hour values, and allowance be made for the proper proportions of outages from other causes.

This type of investigation requires much labor. It is often warranted, however, by the increased rating that can be assigned to a line with reasonable assurance. Incomplete data may be misleading—but still not so much as values chosen by common-sense estimates.

Summary of Conditions in References on Annealing of Copper

Reference Number	Author	Initial Conditions: Strength (Thousand Pounds Per Square Inch)	Initial Conditions: Per Cent Cold Reduction	Initial Conditions: Strand or Gauge	Type Copper: Per Cent Silver	Type Copper: Per Cent Oxygen	Type Copper: Commercial	Test Conditions: Tension While Heated (Thousand Pounds Per Square Inch)	Test Conditions: Test Method	Variables: Time (Hours)	Variables: Temperature (Degrees Centigrade)
1	Wacker	62	71	6	*NS*	*NS*		0	*T*	*x*	100–200
2	Unknown	52	71		*NS*	*NS*		0	*T, E*	*x*	250 and 300
3	Voce	60–57		14–6	0.0017	0.001	*OFHC*	0	*T*	*x*	80
		59–57		14–6	0.001	0.019	*E*				
		59–58		14–6	0.00006	0.030	*EC*				
		50±	50	0.56 inch	0.0017	0.001	*OFHC*	0	*V*	1 and 24	200 and 600
					0.001	0.019	*E*			*x*	250
					0	0.030	*EC*				
4	Beedle	65		6	*NS*	*NS*		10	*T*	48	100–150
5	Zickrick			34	*NS*	*NS*				0.05	225–325
6	Bradley	73			*NS*	*NS*					25–500
7	Talbot	*NS*	*NS*	*NS*	*NS*	*NS*	*E*	0	*J*		
8	Price	48	25	*NS*	*NS*	Low	*E*	0	*T H**		150–1,000
9	Jares	57		*NS*	*NS*	*NS*	*E*	0	*T*	*x*	180
10	Bassett				See reference 24						
11	Bassett	*NS*	*NS*	*NS*	*NS*	*NS*	*E*				
12	Taylor	Soft		6	*NS*	*NS*	*NS*	5	*T*	*x*	
13	Parker	30	0		0.001	0.035	*E*	High	*T*	*x*	200
					0.002	0	*OFHC*				200
					0.054	0	*OFHC* and silver				200 and 250
14	Fuller	*NS*	*NS*	*NS*	*NS*	*NS*	*E*	High	*T*	20	165
		NS	*NS*	*NS*	0.03	*NS*	*L*		*T*	140	300
15	Alkins	63	93	0.26 millimeter	*NS*	*NS*		*NS*		*x*	150–200
16	Pratt	58	62	*NS*	*NS*	*NS*	*E*				
		56	62	*NS*	*NS*	*NS*	*L*		*T, E*	1	*x*
		58	62	*NS*	*NS*	*NS*	*OFHC*				
17	Zeerleder	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	1,000	80
18	H. Moore	60–58		14–19	*NS*	*NS*		0	*T*	*x*	100
		57	69	Strips	0.0005	0.07	*E*	0	*S(T)*	1/2	100–500
		NS	67	Strips	0.1	0	Pure + silver				
		NS	67	Strips	0	0.09	Pure, oxidized				
		53	67	Strips		Pure copper (special)		0	*S*	1/2	100–500
19	Caesar	*NS*	67	Strips	0	0.03	Pure, slightly oxidised				
		NS	67	Strips	0.002	0.08	Pure, oxidized plus silver				
		57–51	69–51	Strips	0.0005	0.07	*E*	0	*S*	*x*	150–300
20	Ofier	62 before aging		6		Present	*E*	0	*T*	*x*	100–200
		59 at test									
21	Wyman	64	58, 85	8	0.024–0.058	0	*OFHC* + silver	34	*E*	*x*	105
		64	58	8	0.024	0	*OFHC* + silver	26–34	*E*	*x*	105
		62	50	8	*NS*	*NS*	*E*	26–34	*E*	*x*	105
		62	50	8	*NS*	*NS*	*E*	24	*E*	*x*	150
		20									
		37		Sheets	0.001–0.132	0.05±	*L*	0	*R*	1/2	200–400
		60									
22	Kinney	70–75	99.8	24	0.001–0.132	0.05±	*L*	0	*T, E*	0.033	275, 300, 325
		70–73	97.5	16	0.001–0.32	0.05±	*L*	0	*T*	*x*	150 and 200
23	Pilling	42–62	25–84		*NS*	0.066	*E*	0	*T*	*x*	100–900
24	Bassett	58	10	Nos. 0.05-inch sheet	0.0005+ 0.0868	*NS*	*E, L*	0	*T, E*	*NS*	0–1,000
25	Rolle	59	62	0.5-inch tube	0.0022	0	*OFHC*	0	*T, E*	1	190–700
		59–63	62–91		0.002	0	*OFHC*	0	*T, R*	1	250–400
26	Webster	56	62–90	6–0	*NS*	0.0285	*E*	0	*T, E*	1	180–800
		59	62–90	6–0	0.0216†	0.033	*L*				
		57			0.002	0.0	*OFHC*	0			
27	Angus	*NS*	33–78	0.28 and 0.31 inch	*NS*	*NS*	*E*	0	*B*	1	100–600
28	Grard	56	57	2 millimeters	*NS*	*NS*	*E*	0	*T*	0.5	100–300
29	Bardwell	66		12	*NS*	0.026–0.07	*E*	0	*T*	0.33	100–400
30	Mathewson	51	50	0.065 inch	0.0005	0.071	*E*	0	*T, E*	0.67	100–1,000
31	Zickrick	62–69			*NS*	0–0.028		0	*T*	0.1	200–400
32	Archbutt										
33	J. L. Gregg										
34	Lorig										
35	Widman	98			0						
					0.24						
36	Hudson	28			0.05	*NS*	Pure +	0	*B*	2	300–500
		50			0.08	*NS*	Silver				250–500
37	Johnson	28–59	0–98	Strip	<0.01	0.05	*E*	0	*T, E, S*	1	200–800
			60		*NS*	0.089		0	*T, E*	0.5	200–470

Symbols:
In column "Commercial Type"
F—"Pure"
E—Electrolytic
L—Lake
C—Chilean

OFHC—Oxygen-free high-conductivity
"*NS*" = Not stated
In column "Test Method"
J—Judgment
T—Tension test

E—Elongation
R—Rockwell hardness
B—Brinell hardness
V—Vickers
S—Scleroscope
H—Hardness

In column "Time" an "*x*" indicates that a time-temperature curve is given
*Apparently tested while hot. Strength lowered at lowest temperature tried.
† High in arsenic and antimony.

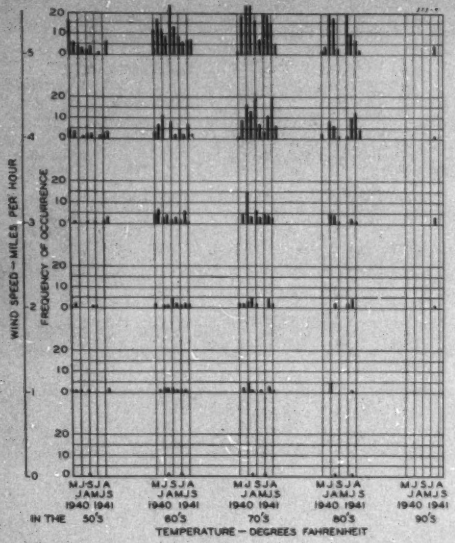

Figure 9. Wind and temperature

Number of hours occurrence of various values at centrally located observatory

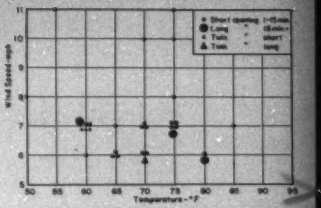

Figure 12. Average wind—temperature

For eight hours following storms that caused 120-kv line openings in 1941. Values at centrally located observatory

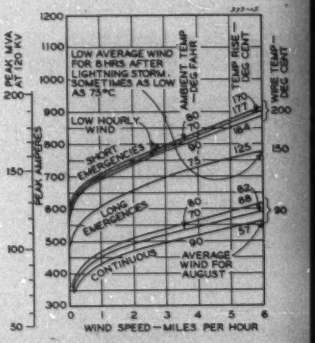
PEAK KVA AT 120 KV
PEAK AMPERES
AMBIENT TEMP —DEG FAHR
TEMP RISE — DEG CENT
WIRE TEMP — DEG CENT
LOW AVERAGE WIND FOR 8 HRS AFTER LIGHTNING STORM SOMETIMES AS LOW AS 7.5 MPC
LOW HOURLY WIND
SHORT EMERGENCIES
LONG EMERGENCIES
CONTINUOUS
AVERAGE WIND FOR AUGUST
WIND SPEED—MILES PER HOUR

Figure 13. Composite chart for selecting wire rating

Number 000 *HD* copper

III. Combination of Data

When we take into account all the considerations discussed, the situation seems involved. If it is visualized as in Figure 13, the relations become clearer. Curves are plotted showing permissible current against wind speed for number 000 copper containing 0.004 per cent silver. Three conditions result:

1. Continuous load (lowest curve).
2. 20-hour single-circuit outage of a twin-circuit 120-kv line.
3. One-hour outage of the same line.

From Figure 4, the permissible temperatures are found to be 90, 150, and 200 degrees centigrade respectively. Using these temperatures and reasonable ambients, from Figures 7 and 8, we derive values of current for the expected range of wind. On this graph we indicate the probable wind-temperature combinations. Thus for case 1 the record shows an average August wind of about six miles per hour. From Figure 13, we see that about 550–600 amperes can be carried. This is not enough to satisfy the conditions for long-time loading. There may be other lower limits. For instance, the 1.5 per cent of calms in August, plus other hours of low wind, may impose a lower limit, even though the permissible temperature is higher.

If we knew more about the effect of intermittent heating upon annealing, we would be justified in developing a method of integrating the temperature-time relationship in a manner similar to the procedure on transformers.

The other curves and weather data shown on Figure 13 should be considered similarly. Such visualization indicates the range of currents that can be reason-

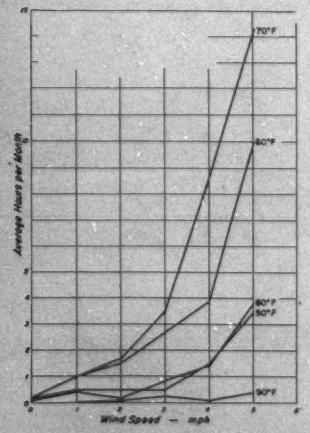

Figure 10. Incidence of low winds at various temperatures

May to September 1940–41, 8 a.m.–5 p.m. Figure shows small number of cases at 90 degrees Fahrenheit all with two miles per hour or more

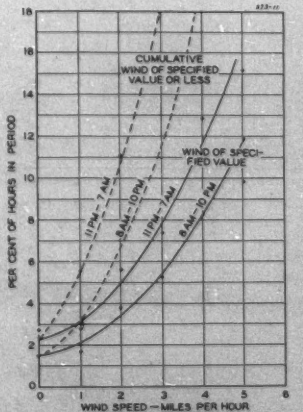
PER CENT OF HOURS IN PERIOD
CUMULATIVE WIND OF SPECIFIED VALUE OR LESS
WIND OF SPECIFIED VALUE
11 PM—7 AM
8 AM—10 PM
11 PM—7 AM
8 AM—10 PM
WIND SPEED—MILES PER HOUR

Figure 11. Frequency and cumulative frequency of winds in July and August 1935–40

Values at centrally located observatory

ably used and shows the desirability of adjusting the ratings to each set of conditions encountered in operation.

This report summarizes a great deal of information of electric rating of overhead wires on a thermal basis. It gives a reasonable working basis for most cases but indicates there are many gaps to be filled: in finding how intermittent heating under tension and vibration affects heating, the temperature limits on wire coverings, resolving some discrepancies in temperature-rise data, in computing expectancies of loads and weather combinations, and in developing a simplified method of applying these data in the field.

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* Especially good reports.

Advantages of High-Speed Traction Motors

C. A. ATWELL
MEMBER AIEE

THE present use of high-speed light-weight propulsion motors on various types of traction vehicles is the result of an engineering evolution. An important phase of this development began approximately fifteen years ago, but the greatest progress has been during the past seven years. The motors resulting have definite advantages over their larger and heavier predecessors, and it is the purpose of this paper to point out and evaluate the more important of these advantages.

Historical

Prior to 1927 practically all of the traction motors in use on streetcars and interurban and subway cars were of the axle-hung type, geared to the wheels by a pinion on the armature shaft and a gear on the car axle. During the middle 20's there was a demand for motors of much lighter weight for use on gas-electric and trolley coaches. This demand was met by the design of motors of considerably higher speed and connected to the wheels through propeller shafts and automotive-type axles. These early high-speed motors were somewhat hybrid in construction, utilizing experience obtained from the lightest weight axle-hung streetcar motors and those used on electric battery trucks at that time. It is significant that nearly all of them used commutating poles and all employed anti-friction armature bearings.

In 1928, the Westinghouse double-reduction *W-N* gear-unit drive was developed for streetcars. This required a high-speed motor which had approximately 35 per cent of the weight and double the maximum armature speed of its axle-hung predecessor. Since that time, much design, research, and operating experience has been combined to produce the modern motors that are used today on the various forms of electrically driven city and intercity transit vehicles and some types of mining and railway locomotives. The following discussion enumerates and evaluates the principal advantages of these motors:

Paper 43-75, recommended by the AIEE committee on land transportation for presentation at the AIEE South West District technical meeting, Kansas City, Mo., April 28–30, 1943. Manuscript submitted January 13, 1943; made available for printing March 30, 1943.

C. A. ATWELL is design engineer in the transportation engineering department of Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa.

Reduced Size and Weight

The principal feature that permits motor designs of decreased size and weight is the gearing used which allows higher-speed armatures. The maximum gear reduction usable on the axle-hung motors was around 6 to 1, and reductions used were usually around 5 to 1. This was because of an inherent limitation in gear reduction in the tie-up between the center lines of armature and axle, gear-tooth strength, and clearance from gear case to rail. With the motor separated from the gears, a gear ratio is selected which allows the motor armature to rotate at its highest economical speed. The result is that traction-motor gear ratios from 6 to 1 up to 22 to 1 are now used, depending on the application and type of vehicle.

The size and weight of a motor armature are approximately proportional to its torque. Horsepower is proportional to the product of speed and torque. If a given horsepower rating can be obtained from more speed and less torque, the armature is smaller in proportion to the decrease in torque. Another reason for smaller armatures on recent motors is the saving in space effected by modern insulation of the armature coils. The development of thinner and stronger mica and glass tapes and wrappers has made this possible. Any decrease in armature diameter by improvements such as this means that the rotational speed can be increased further, and thus a still smaller armature for the same horsepower can be used. A smaller armature carries with it a reduced field structure, and therefore the whole motor is reduced in size and weight. Figure 1 shows a comparison of motor weights. The comparison is between the latest light traction axle-hung motors *A*, and modern high-speed motors developed since 1935–*B*. The weights given are exclusive of gears or gear housings in both cases.

Figure 2 shows comparatively how the size of traction motors having a one-hour rating of 125 horsepower has varied over a period of years.

One of the advantages of the reduced motor size is the saving in material. The saving of copper is especially important as an aid to the war effort. The copper saving in motors used on 2,100 Presidents Conference Committee streamlined streetcars recently built in this country and Canada is approximately 1,250,000 pounds. This saving is estimated by comparing the weight of copper in the present motors used on these cars with the weight of copper in the most recently designed axle-hung streetcar motors of the same rating.

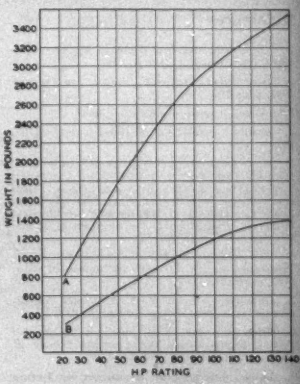

Figure 1. Motor weight comparison

A. Weights of most recent axle-hung streetcar and interurban car motors

B. Weights of modern high-speed traction motors

Another important advantage of decreased motor size and weight is the allowable reduction in truck or chassis size and weight. Modern streetcars, trolley-coach, or Diesel-electric-coach construction would not be possible if the modern light-weight motors were not available.

Increased Ventilation

The higher-speed armature permits a fan design that provides increased ventilation. This causes the continuous rating more nearly to approach the one-hour rating. The slower-speed motors had continuous ampere ratings that were between 60 and 75 per cent of the one-hour rated amperes. The high-speed motors have continuous ratings between 80 and 90 per cent of the one-hour rating.

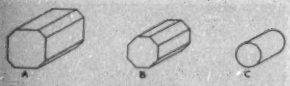

Figure 2. Graphic comparison of traction motor body size

A. Rated 600 volts, 125 horsepower, 275 rpm (developed in 1909)

B. Rated 600 volts, 125 horsepower, 800 rpm (developed in 1915)

C. Rated 300 volts, 125 horsepower, 2,000 rpm (developed in 1939)

Higher Efficiency

The high-speed motor is fundamentally more efficient than a lower-speed motor of the same voltage and rating. This is because fewer conductors of shorter length are required both in the armature and field coils. This reduces the copper I^2R loss which is a major part of the total loss especially at heavy accelerating loads. The iron losses and friction losses of the high-speed motor may become greater at low values of tractive effort, but the small per cent of operation at these low loads makes the reduction of efficiency here unimportant.

Figure 3 shows a comparison of motor efficiencies of two 125-horsepower, 600-volt traction motors. *A* has a rated speed of 2,440 revolutions per minute and maximum speed of 4,500 revolutions per minute. *B* has a rated speed of 800 revolutions per minute, maximum 1,800 revolutions per minute.

Better Commutation

The modern high-speed motors have better commutation than their predecessors. This is partly inherent in the higher-speed design and partly due to increased knowledge. The so-called "reactance" voltage that tends to cause sparking at the brushes is dependent mainly on the number of armature conductors, armature size, and speed. The higher-speed armature has less conductors and is smaller, and this more than offsets the effect of increased speed. The use of the full number of commutating poles and brush arms, as well as greater care to avoid saturation of the commutating-pole magnetic circuit at heavy loads, have also been factors in producing improved commutating and flashing characteristics. Figure 4 shows a comparison of reactance or "sparking" volts for a low-speed and a high-speed motor.

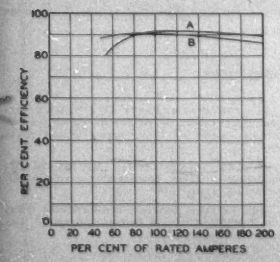

Figure 3. Comparison of motor efficiency

A. Rated 600 volts, 125 horsepower, 2,440 rpm

B. Rated 600 volts, 125 horsepower, 800 rpm

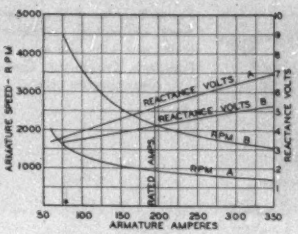

Figure 4. Commutation comparison

A. Motor rated 600 volts, 140 horsepower, 930 rpm

B. Motor rated 600 volts, 140 horsepower, 2,000 rpm

Improvements in Mechanical Construction

Mechanical improvements have gone along with motor speed increases. Some of them have been stimulated by the higher speeds. Examples of these are accurate dynamic balancing, better commutator seasoning, and more accurate commutator surfacing. Once shop methods for performing these operations were established, they were found to be as easy to do as the less adequate methods formerly used for slower-speed armatures. The types of motor mounting have been simplified so that motor frames have become simple cylinders of rolled steel. Easily removable, simple commutator covers are used, allowing easy inspection of commutator and brush holders. Motors are being mounted so that they have the same spring-supported ride as

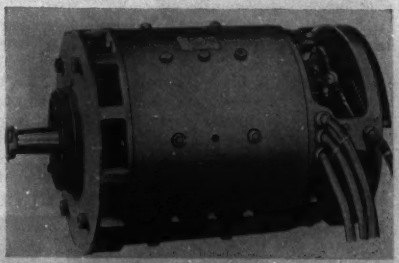

Figure 5. High-speed 125-horsepower 300-volt motor for use with double- or triple-reduction gearing on Diesel-electric switcher locomotives

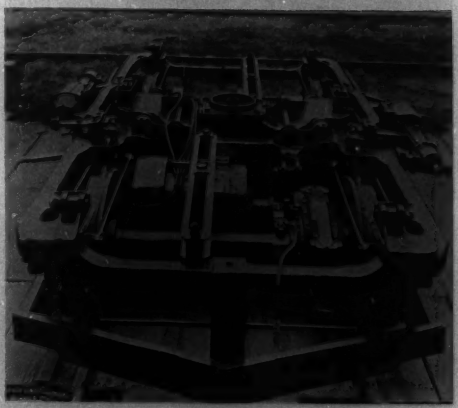

Figure 6. High-speed motors and *W-N* gear unit mounted in truck of high-speed trolley train

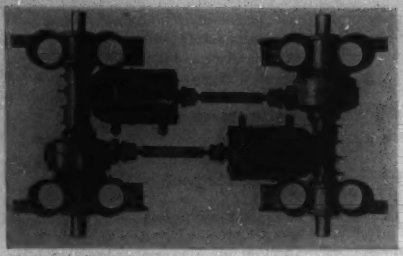

Figure 7. Mounting arrangement of motors, propeller shafts, gear units, and axles in Presidents Conference Committee streetcar truck

Figure 9. Armature of 140-horsepower trolley-coach motor complete with bearing housings and bearings, weighs only 525 pounds

the passengers. This permits constructional simplification not allowable on a motor receiving direct impacts through wheels and axle. An example of this is the elimination of field-coil springs. Field coils are now made accurately to size and clamped solidly between a flat washer at the pole tip and the frame at the base of the pole. In the design of the stator, any improvement that decreases the frame diameter for a given armature diameter pays almost double in weight reduction. It not only reduces the amount of iron in the magnetic circuit but shortens the length of magnetic path, thus rapidly reducing the field turns required for the same flux.

Improved Insulation

Improvements in insulating materials and treatment processes have been numerous during the past few years. These improvements have been incorporated in the new motors as they were designed. Class *A* insulation is rarely considered in the design of new traction motors. Class *B* conductor coverings, tapes, and slot wrappers have been improved so that they are thinner, yet have increased dielectric and mechanical strength along with the ability to withstand high temperatures. Improved insulating varnishes and methods of treating coils before and after their assembly have made windings less liable to grounds.

Ease of Maintenance Increased

Ease of maintenance and therefore the cost of maintenance have been considered constantly in the design of modern high-speed traction motors. The reduced labor of handling because of the smaller size of complete motor and parts is an important factor. The use of grease-lubricated roller or ball bearings and a bearing housing construction that permits removal from the frame without exposure of the bearings or lubricant to dirt is another. With the present bearing and shaft construction, shaft breakages are practically unknown and bearing replacements are very infrequent. The cost of renewal parts and the difficulty of their replacement both have been reduced in this type of motor.

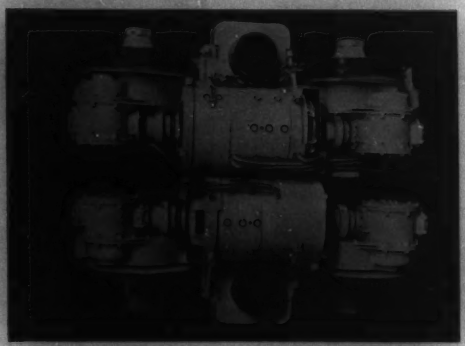

Figure 8. High-speed traction motors mounted in Differential Car Company "axleless" truck for mining locomotives

Conclusion

The modern high-speed traction motor as used today may be said to be the product of an evolutionary development and is based on sound engineering fundamentals. The outstanding advance that has been made in reduction in weight and size has been accompanied by better commutation, increased ventilation, higher efficiency, and improved mechanical construction. The various improvements that have accompanied the increase in speed have combined to produce a motor that is easier to place in a truck or chassis and is more trouble-free and easier to maintain than its predecessors.

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2. Modern Transportation Motors, H. W. Gouldthorpe. *Mass Transportation*, volume 36, March 1940, pages 64–6.

3. The Traction Motor Gets Reducing Dirt, C. A. Atwell. *Electrical Journal*, volume 33, December 1936, pages 538–9.

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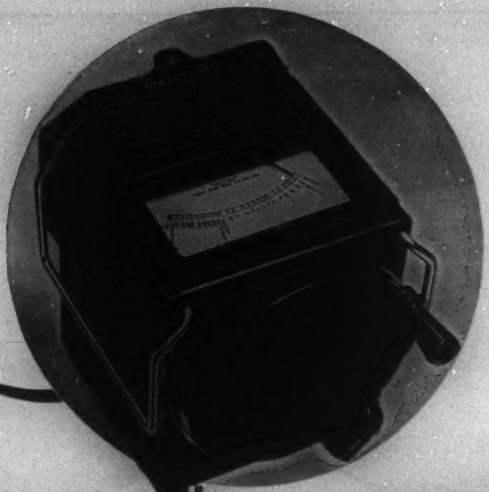

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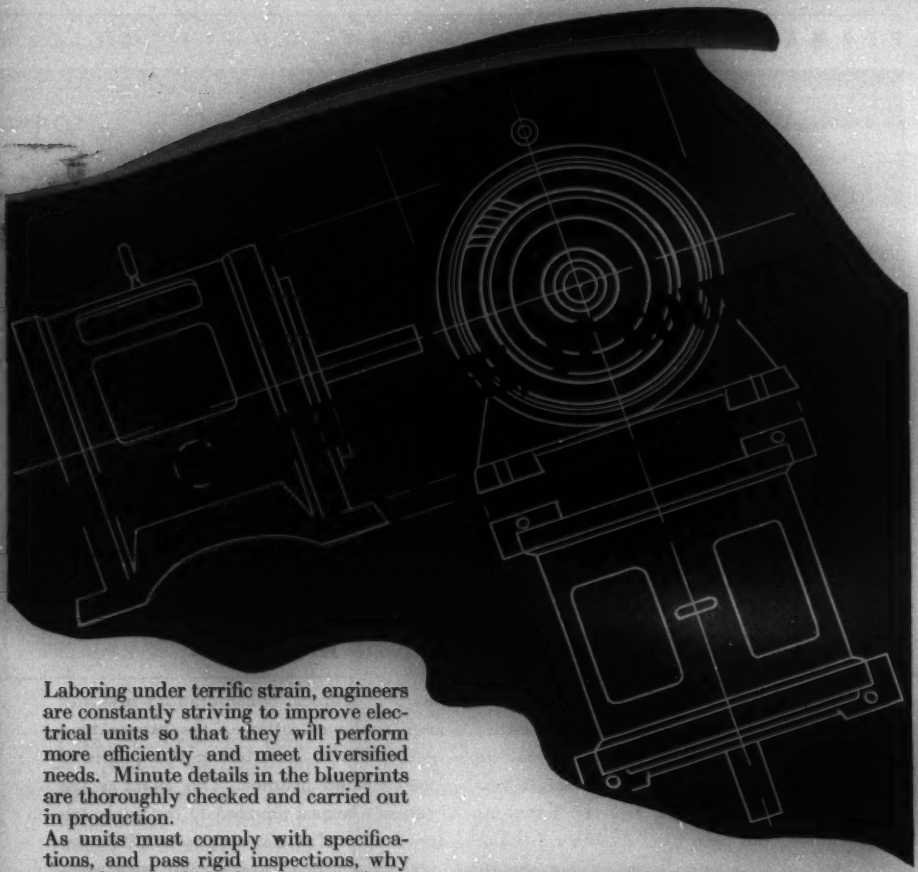

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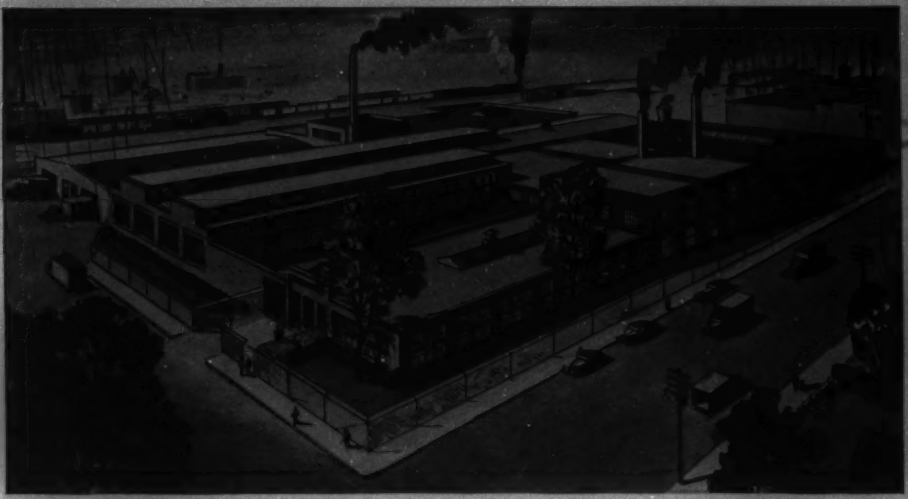

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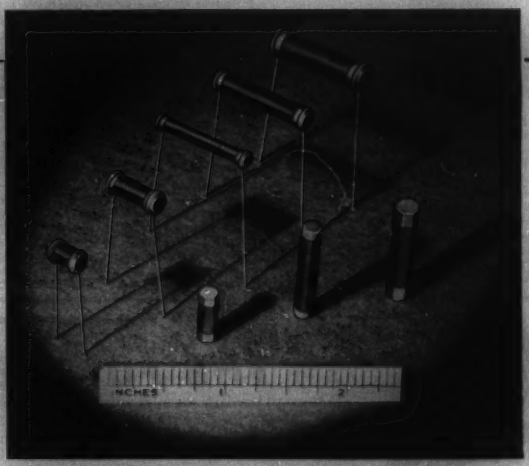

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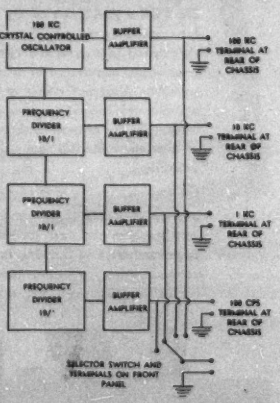
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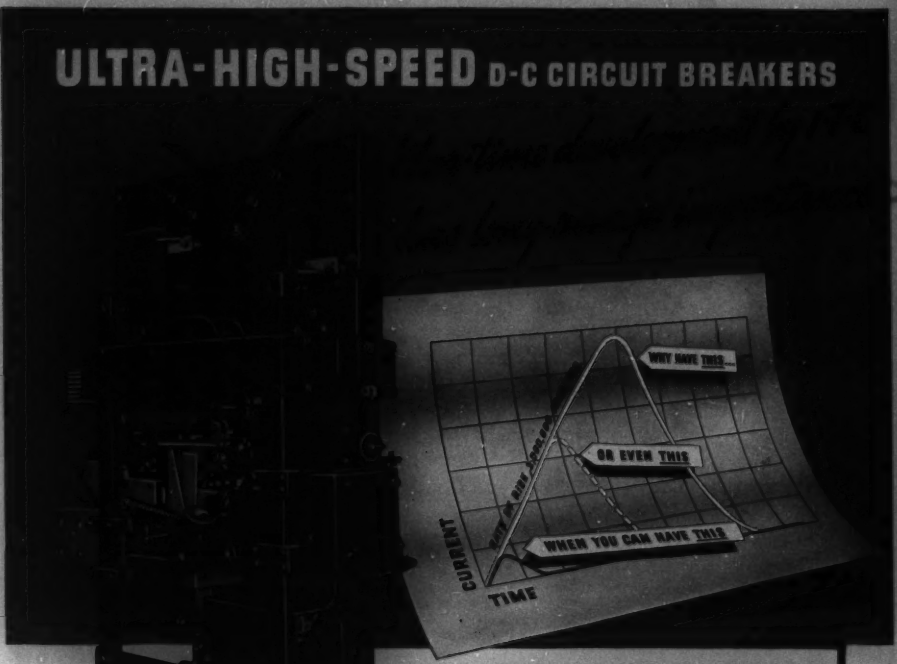

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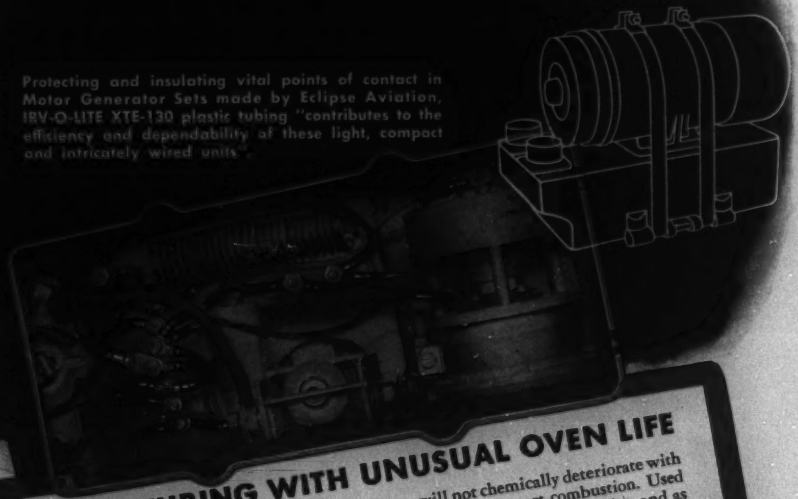

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Elongation	240%
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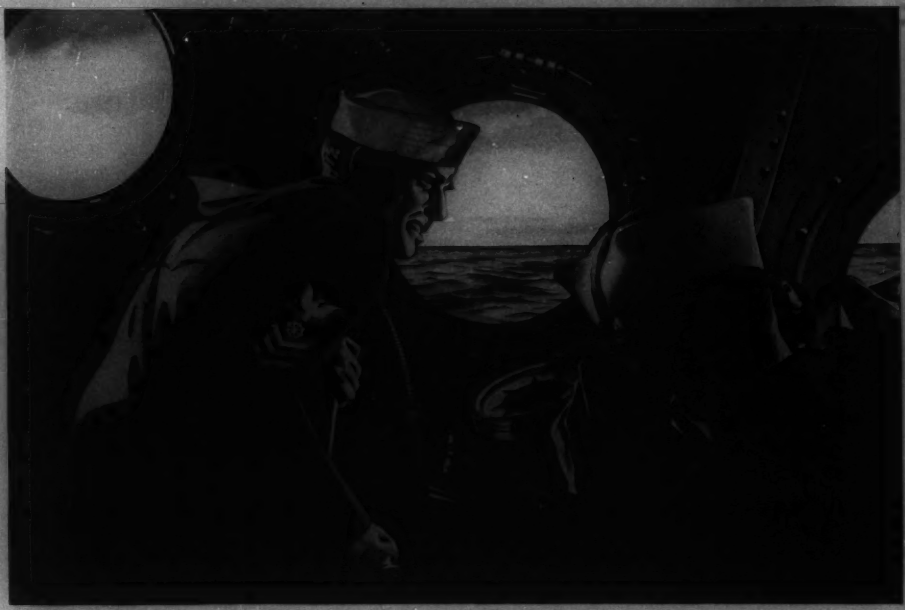

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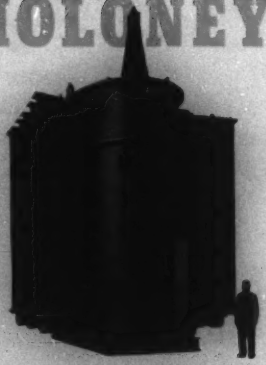

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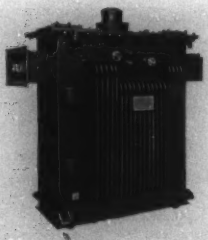

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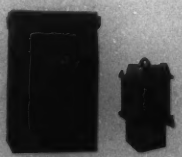
MOLONEY ELECTRIC COMPANY
ST. LOUIS, U. S. A.

Moloney Conventional Distribution Transformer, oil-cooled, for outdoor pole or platform mounting. Sizes 1½ Kva to 500 Kva. Voltages up to 66,000 volts. Illustration typical of sizes 75 and 100 Kva, 7200 to 120/240 volts.

Moloney Completely Self-Protected Transformer, oil-cooled, equipped with built-in lightning and secondary overload protection. Sizes 1½ to 50 Kva. Voltages 2400 to 13,800 volts. Illustration typical of sizes 1½ to 25 Kva, 7200 to 120/240 volts.



Moloney General Purpose Air-Cooled Transformers with Class A insulation. For industrial use to serve lighting and small power loads. Left illustration typical of sizes 15 to 50 Kva. Right illustration typical of sizes 1 Kva to 10 Kva. Voltages 600, 480 or 240 to 120/240 volts.

Moloney Transformers for every purpose

- Power Transformers
- Unit Substations
- Conventional Distribution Transformers
- Completely Self-Protected (CSP) Transformers
- Load Center Transformers
- Askarel (non-inflammable liquid) Cooled Transformers
- Air-cooled (Class A and Class B insulated) Transformers
- Constant Current Street Lighting Transformers
- Vault Type Transformers
- Submersible Type Transformers
- Furnace Transformers
- Shipboard Transformers
- Industrial Transformers
- Network Transformers

Use This Check List

WHEN INSTALLING BRUSHES ON YOUR ELECTRICAL EQUIPMENT

1. See that all terminals are securely fastened to the brush holder support.
2. Remove dirt and grit from brush holders.
3. Provide 1/16" to 1/8" clearance between commutator and nearest portion of brush support in reaction and box type brush holders. Less clearance is sometimes preferable on small motors.
4. Keep angular position of all brush holders uniform with respect to the commutator.
5. Check neutral point and space the brush arms equidistant about the commutator.
6. See that toes of all brushes on each arm are parallel with commutator segment.
7. To prevent streaking of commutator, stagger brushes in positive and negative pairs.
8. Seat new brushes on commutators and rings accurately with sandpaper or a brush seating stone.
9. Adjust brush spring pressure to conform with manufacturer's recommendation.

Care exercised in the installation, fitting and adjustment of brushes increases life, improves performance and eliminates many of the possible causes of interrupted service.

Carbon Graphite and Metal Graphite BRUSHES

NATIONAL CARBON COMPANY, INC.

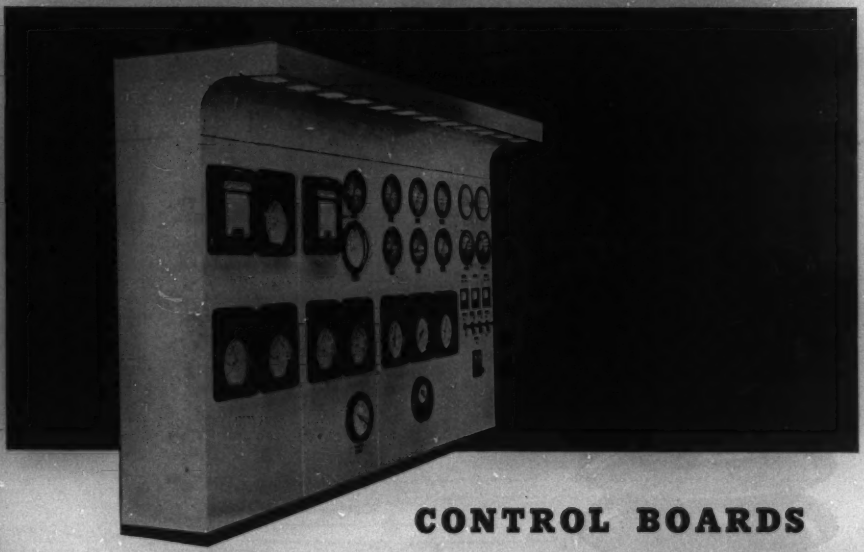
Unit of Union Carbide and Carbon Corporation

CARBON SALES DIVISION, CLEVELAND, OHIO

General Offices: 30 East 42nd St., New York, N.Y.

Branch Sales Offices: New York, Pittsburgh, Atlanta, St. Louis, San Francisco

KIRK & BLUM
SHEET STEEL *fabrication*



CONTROL BOARDS
for UTILITIES POWER STATION

One of a group of Control Boards, for boilers, boiler feed pumps, turbines and evaporators, fabricated by Kirk & Blum master craftsmen, with faithful adherence to plans and specifications of The Columbia Engineering Corp., at the Columbia Power Station of The Cincinnati Gas & Electric Co.

Instrument face of this control board assembly is ¼ inch steel plate. Sides, barriers and door panels, which comprise back of this fully enclosed control board assembly, as well as lighting cabinet on top, are fabricated from No. 10 gauge steel of all welded construction.

The Kirk & Blum Organization of engineers and mechanics, with a background of more than 36 years of sheet metal fabrication, has the "know how" to properly interpret your plans and fabricate your products with craftsmanlike precision. You'll save time and costs when Kirk & Blum is assigned to fabricate your Cubicles, Bus-way Enclosures, Switch Gear Housings, Switch Board Panels, Control Desks Control Panels and other specialized sheet steel requirements.

Send us your blue prints for prompt quotations.

Accurate Sheet Steel Fabrication Capacity 3/8 inch and lighter.

Send for any of the following Booklets:

"Data on KIRK & BLUM Production Facilities"

"Dust Collecting Systems in Metal Industries"

"Fan Systems for Various Industries"

"Blower Systems for Woodworking Plants"

"Industrial Ovens"

"Cooling Systems for the Glass Industry"

THE KIRK & BLUM MANUFACTURING CO.
AN ORGANIZATION OF ENGINEERS AND MECHANICS
2855 SPRING GROVE AVE. CINCINNATI, OHIO

Large Industrial Plants *rely upon* G & W POTHEADS

for full cable protection

Electric cables are important arteries in America's high production effort. The cable ends must be definitely sealed and generously insulated to prevent service interruptions. *G & W POTHEADS* with "Resistoyl" gaskets and properly designed joints prevent the entrance of moisture and the leakage of cable impregnating compound. They are available for all voltages and conductor sizes. Many sizes can be shipped from stock.

Send for

BULLETIN No. 392
Listing over 4000 G & W Potheads

BULLETIN "DIP"
Directions for installing Potheads

G & W ELECTRIC CABLE DEVICES

G & W ELECTRIC SPECIALTY CO.
1780 DANTE AVENUE CHICAGO, ILLINOIS
IN CANADA—POWERLITE DEVICES, LTD., TORONTO

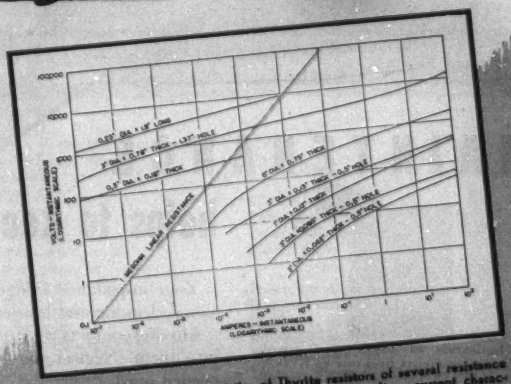
POTHEADS . . . BOXES . . . OIL FUSE CUTOUTS . . . OIL SWITCHES AND MULTIPLE CIRCUIT OIL DISCONNECTS

DESIGN ENGINEERS — CAN YOU USE A RESISTANCE MATERIAL IN WHICH I varies as E^4?

THYRITE

MAY BE THE ANSWER TO SOME OF YOUR CIRCUIT PROBLEMS

THYRITE* is a silicon-carbide ceramic material, dense and mechanically strong, having nonlinear resistance characteristics—the resistance varying as a power of the applied voltage. Its resistance characteristic is stable, and substantially independent of polarity or frequency. Thyrite has been used for many years in many important applications, including electronic. Thyrite can be produced in various shapes and sizes (those which can be successfully molded).



Typical volt-ampere characteristics of Thyrite resistors of several resistance levels and power ratings. Note that the nonlinear voltage-current characteristic extends over an extremely wide current range. Compare it with the characteristic (orange line) of a 1-megohm linear resistor.

Here are some of its MANY APPLICATIONS

- For protective purposes (to limit voltage surges)
- As a stabilizing influence on circuits supplied by rectifiers
- As a potentiometer (The division of voltage can be made substantially independent of load current)
- For the control of voltage-selective circuits, either independent of or in combination with electronic devices

*Reg. U.S. Pat. Off.

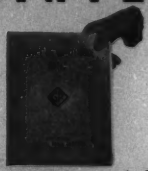
The nearest G-E office can tell you what data should be submitted as a basis for a quotation. Or write direct to General Electric, Section 16-250, Pittsfield, Mass.

GENERAL ELECTRIC

SERVICE AND MAINTENANCE NOTES
for the
TYPE 650-A IMPEDANCE BRIDGE
1.0 GENERAL MAINTENANCE ★
1.1 From time to time all switch blades and contacts and the contact surfaces of the four potentiometers should be cleaned and lubricated. For cleaning, it is recommended that a solution of half ether and half alcohol be used, followed by a few light strokes with crocus cloth. A very light smear of petrolatum should then be applied, except on the GENERATOR and DETECTOR switches and the cam switch on the CAL-ADJUST switch shaft. In

MAINTENANCE

helps to keep them in service



★ Thousands of users of General Radio instruments find our SERVICE AND MAINTENANCE NOTES useful in keeping their instruments in service. If you do not already have these notes for your GR instruments, send us the type numbers and serial numbers of the equipment you have. Your service notes will be forwarded promptly.

Your impedance bridge, like your automobile, needs occasional cleaning and lubrication.

Moving contacts wear out faster when dry and when dust gets into them. Neglect may result in failure when equipment is needed most.

Periodic maintenance will go a long way toward keeping your electrical test equipment in trouble-free operation. Increased life and reliability will more than repay you for the effort. Set up a definite maintenance program for your test equipment.

GENERAL RADIO COMPANY · Cambridge, Massachusetts
NEW YORK LOS ANGELES

They work together better . . .
because they can talk together

From a thousand feet up
The burning airdrome
Looks like
A "pushover" . . .

But
When you get
Right down to earth
It turns out to be
Anything but.

Suddenly the trees
To the right
Start throwing lead —
And your men
Are still hanging
Like clay pigeons
In their harnesses.

* * *

What a break
That you're equipped
With a
Two-way
Radio.

What a break
That you can tell your trouble
To a friendly
Fighter plane.

* * *

Today, communication equipment
Designed and manufactured
By I.T.&T. associate companies
Is helping Uncle Sam's fighting forces
Work together
On land, sea and in the air . . .

Tomorrow, the broad experience
Of I.T.&T.
In the field of communications
Will help build a better world
For every man.

International Telephone and Telegraph Corporation *67 Broad St., New York, N. Y.*

I T&T

Manufacturing Associate:
Federal Telephone and Radio Corporation

Why Stu doesn't need to know "overload" exists

Stu is top-turret gunner on a 4-engine bomber.

He knows a whale of a lot about operating his turret and his gun. But he doesn't know anything about "overload" . . . doesn't care to know . . . doesn't have to know.

Here is why.

Some time ago, electrical-design engineers recognized that the motors operating any gun turret would have to meet extreme conditions of overload. The turrets stop and start quickly in battle. Sometimes they must work against the air stream. They must be *small* in comparison to the horsepower they deliver.

Taking care of this overload naturally involved an insulation which could stand a high temperature rise. To get such an insulation, the electrical industry sought out Fiberglas* Electrical Insulations and combined them properly with the newest impregnants.

In addition to withstanding overload, these Fiberglas combinations are very light in weight, have a low space factor, and excellent moisture resistance.

Today, almost all American aircraft contain motors no larger than your fist up to babies big enough to start the engines. Most of them are Fiberglas-insulated.

The aviation industry's demands for Fiberglas have been constantly growing because of an *increasing* use of Fiberglas in an air force which is *expanding*.

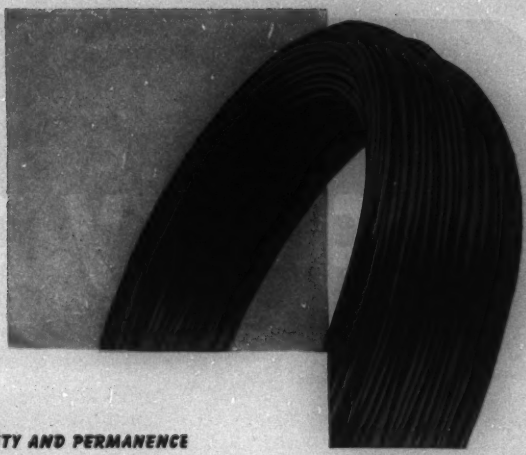
Besides, both Army and Navy are using more and more Fiberglas in many other types of equipment as well as for wire and cable insulation.

Although Fiberglas production was greatly expanded last year and is now being increased every month, vital war demands have so far kept pace with this expansion.

These are the reasons why your electrical distributor may not have been able to fill your orders promptly. *Owens-Corning Fiberglas Corporation, Toledo, Ohio. In Canada, Fiberglas Canada, Ltd., Oshawa, Ontario.*

Fiberglas Electrical Insulations

*T. M. Reg. U. S. Pat. Off.



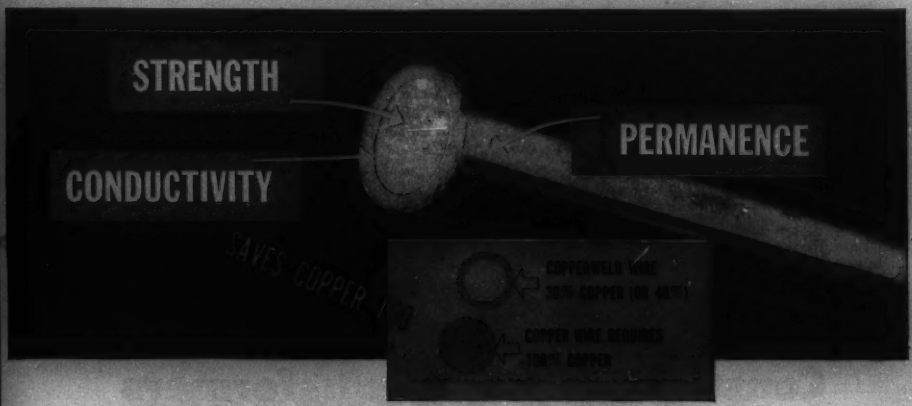
TODAY, MORE THAN EVER,

YOU REQUIRE COPPERWELD'S

Tested STRENGTH, CONDUCTIVITY AND PERMANENCE

For over a quarter of a century electrical engineers have learned to depend on the copper-steel combination of Copperweld for its inherent strength, conductivity, and permanence. Every coil of wire must pass the following dependability tests: conductivity, breaking strength, elongation, bend, perfection of weld, surface, kink, and required copper thickness.

The steel and the copper combined in Copperweld
do many jobs better than either metal could do them alone.



Copperweld Steel Company

GLASSPORT, PENNA.

MANY TIMES every day "surprise attacks" occur along your power line. Some heavy user momentarily stops operation. A sudden over voltage slams like lightning into delicate machines, precision tools or precious vacuum tubes. You can't see these blitz attacks but you can't escape seeing the results—higher percentage of rejections, damage to sensitive instruments, premature failure of expensive electronic tubes.

Every unit, however small, is responsible for its own security. This cardinal rule of combat applies in production too. That is why, everywhere in industry, you will find SOLA CONSTANT VOLTAGE TRANSFORMERS on duty at important "outguard" posts.

Sola "CVs" are especially designed to protect against surprise overload assaults. They will absorb voltage sags and surges as great as 30%—and still feed constant, rated voltage to your machines. Sturdy Sola sentinels ask no relief. Day and night, without care or supervision, they stick to their posts—instantaneous in action, without moving parts, self-protecting against short circuit.

Many vital points in your production system are vulnerable to attack. Secure them with Sola "CVs". SOLA CONSTANT VOLTAGE TRANSFORMERS are built in standard units from 10VA to 15KVA capacity, or in special units to your specifications.

Note to Industrial Executives: *The problems solved by Sola "CV" transformers in other plants and products may have an exact counterpart in your own. Find out. Ask for bulletin ACF-74.*

SOLA
Constant Voltage Transformers

Transformers for Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago, Ill.**

Dunco Sensitive

RELAYS FOR LOW-POWER USES

TWICE TESTED . . . BALANCED TO STAND VIBRATION

For vacuum tube circuits—for the protection of delicate instrument contacts—for alarm circuits—for exacting temperature control—wherever the need is for dependable relays to operate on very low coil circuit power, you will find Dunco Sensitive Relays unexcelled.

Each unit is specifically "tailored" to its specific job. Each has its moving parts carefully balanced, making it suitable for use where vibration is encountered. Each is twice-tested before leaving the factory.

Shown here are sensitive relays of the Dunco Series 28 (high-sensitivity), and Series 29 (medium-sensitivity) types available in various styles of mounting. Numerous sensitive Dunco Midget Types are likewise available for similar low-power uses where small size and light weight are important factors.

DUNCO CATALOG AND RELAY DATA BOOK

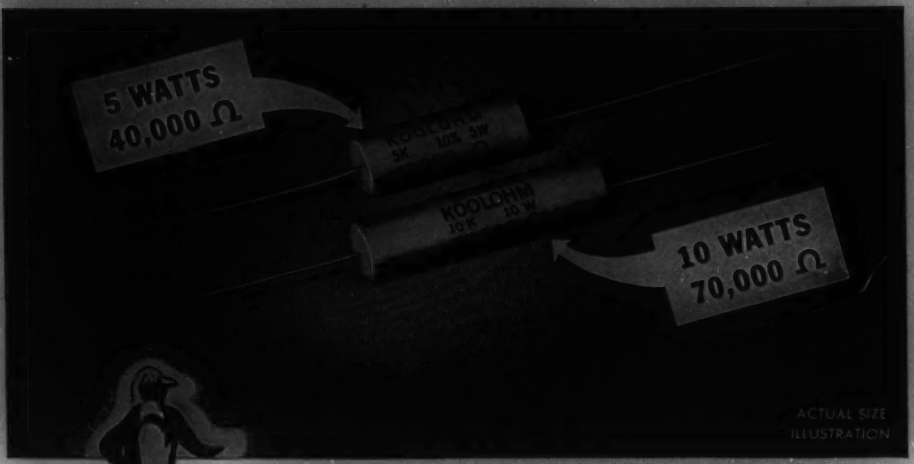
You can find the right relay for almost any application in the 48-page Dunco Catalog—also helpful engineering information and suggestions on relay selection and use. Copy upon request.

STRUTHERS DUNN, Inc.

1321 ARCH STREET PHILADELPHIA, PA.

LET DUNCO DISTRICT ENGINEERS IN 28 STRATEGICALLY LOCATED CENTERS HELP SOLVE YOUR RELAY PROBLEMS

THESE RESISTOR WATTAGE RATINGS MEAN WHAT THEY SAY



...Regardless of the ohmic values

If it's a 5-watt Koolohm, use it at its full 5-watt rating—regardless of whether it has a 1 ohm or a 40,000 ohm value! If it's a 10-watt Koolohm you can count on it dissipating a full 10 watts whether the resistance value is 1 ohm or 70,000 ohms!

In brief, there's no need to "play safe" with Koolohms. You don't have to use a larger resistor than you actually require. You can forget your worries as to whether the wire size is big enough to carry the current and the resistor body large enough to withstand the temperature rise involved. *You can use any Koolohm at its full wattage rating—any time, anywhere!*

This freedom of use is made possible because Koolohm design is based upon a time-tested, inorganic insulating material. This is sintered on the wire *before it is wound*—at 1000° C.! The insulation is flexible, and has a dielectric strength of 350 volts per mil at 400° C.!

Samples free to industrial users. Catalog on request to all who are interested in better, more dependable resistors.

SPRAGUE SPECIALTIES CO., Resistor Division, North Adams, Mass.

KOOLOHM WIRE IS 2¼ TIMES LARGER
Although Koolohm Resistors themselves are no larger—often smaller—than ordinary resistors, their wire is 2¼ times larger in actual cross-sectional area! This is especially important in the high resistance values where very fine wires so often fail to carry the currents involved in power resistor operation, or to withstand the corrosive effects of operation in high humidities. *Play safe* with Koolohms!

KOOLOHM

POWER WIRE WOUND RESISTORS AND METER MULTIPLIERS

SALUTE TO THE WORLD OF TOMORROW!

DESIGNERS
AND MANUFACTURERS
of all types of precision electrical apparatus including
D.C. & A.C. Motors for specialized purposes
Aircraft Generators
Aircraft Engine Starters
Alternators
Motor Generators
Electric Pumps
Motors with Governors
Gyros, etc.

THINGS will be—must be—different after the war. Men are fighting today not only to maintain civilization—but to improve it.

The motor cars, the planes, the homes, the electrical appliances of the future will be fantastically different — efficient beyond our present dreams.

Industrial leadership in this world of tomorrow will be won by today's most forward-minded organizations. This new spirit of progressive enterprise is typified by Small Electric Motors (Canada) Limited.

Here, where all activities are geared to war production, the groundwork is already set, through research and invention, for revolutionary peace-time products for ships and planes—for homes and factories!

Small Electric Motors (Canada) Limited

LEASIDE • TORONTO 12 • CANADA

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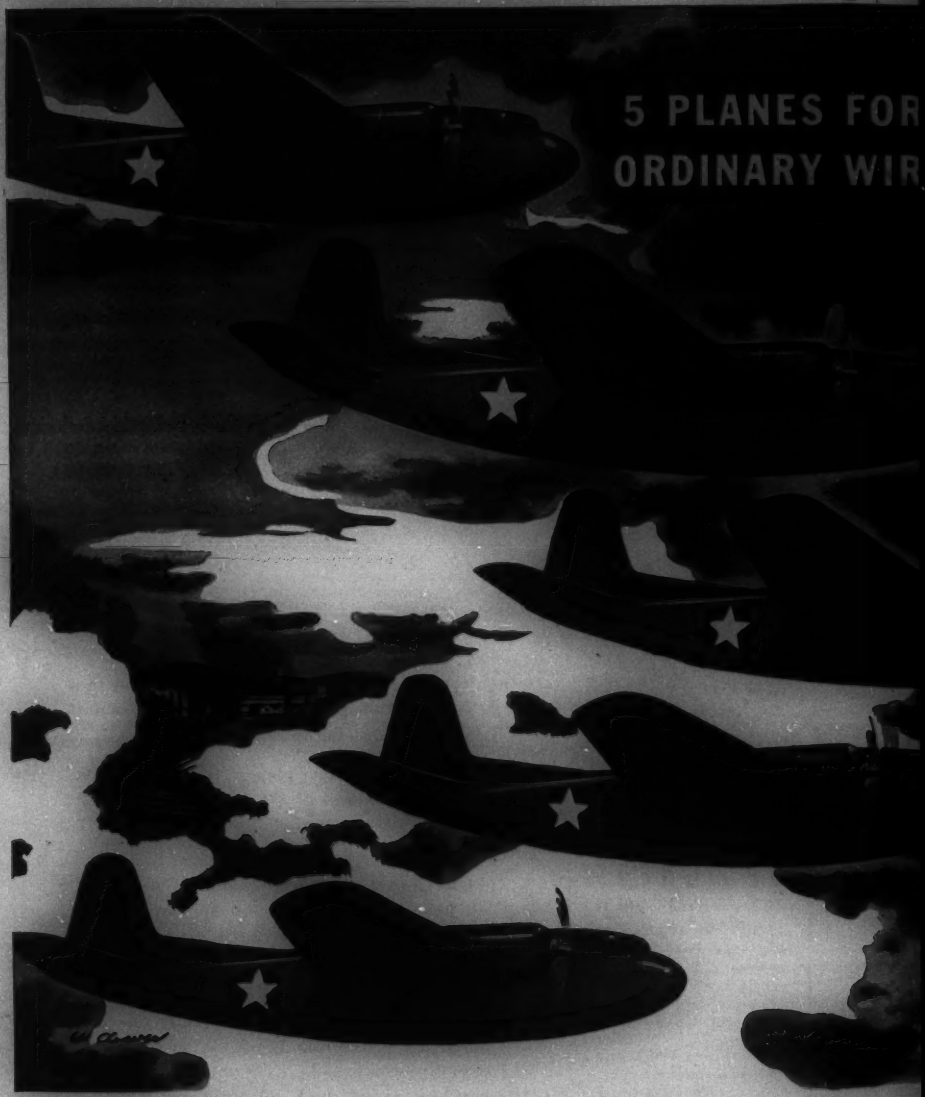


Listen to the Philharmonic Symphony Program over the CBS network Sunday afternoon 3:00 to 4:30 E.W.T. Carl Van Doren and a guest star present an interlude of historical significance.

°REG. U. S. PATENT OFFICE

UNITED STATE

1 PLANE FOR U. S.
LAYTEX* ASSAULT WIRE

Time is one of our best allies. The faster we can get men and material up to the front, the sooner the war will be won... our fighting men return. That's why transport planes are playing a bigger and bigger part in the Service of Supply... and why Laytex Assault Wire fits ideally into the picture of air transport.

Laytex Assault Wire—made especially for front-line service—requires only 1/5 the space in transport of ordinary communications wire. If Laytex Assault Wire had not been developed and ordinary wire had to be shipped for the same use, by air, four additional planes would be required for transport... planes needed for men, medical supplies, food... whatever must reach the front in a hurry.

Laytex Assault Wire resists concussion and a wide range of temperature changes. It is strong, tough, will not abrade or peel excessively. Laytex is highly flexible. It is waterproof and is closely bonded to accurately-centered electrical conductors. All these qualities are the inevitable result of the unique Laytex Process which applies the compounded, purified insulation in liquid form.

Laytex Assault Wire weighs less than 30 lbs. per mile; has a breaking strength greater than 50 lbs. per conductor; a talking distance of more than five miles.

Laytex ASSAULT WIRE

REG. U. S. PAT. OFF

FREES 4 PLANES FOR EMERGENCY TRANSPORT

1230 SIXTH AVENUE ROCKEFELLER CENTER · NEW YORK

RUBBER COMPANY

American Fighting Machines Require Littelfuses

Millions of Littelfuses are guarding countless electrical circuits of our fighting equipment in the air, on land, on sea, and undersea

On Guard Where Protection is Vital

Every circuit built into a plane, tank, boat, or submarine must withstand unprecedented shock, surges and vibration.

Precision instruments, dials, indicators, radio, all delicate electrical mechanisms of aircraft are subjected to shocks of dives from 60° below zero to 120° above—*in seconds*. Fuses must not fail.

Littelfuses are engineered to meet all conditions: By mechanical depolarization, new protection against severest vibration; by spring-and-link elements protecting smaller fuses; by reinforcement counteracting expansion and contraction; by patented locked cap assembly sealing fuse element against moisture and preventing caps from loosening.

The Show-Down Sets the Pace

Besides supplying Army and Navy requirements, over 4000 manufacturers depend on Littelfuse products for sure and uninterrupted performance of their equipment for war use.

Mechanical Depolarization

New protection from severest shock and vibration from any direction effected by twisting fuse elements at 90°.

Non-Crystallizing Fuse Elements

Spring-formed "goosenock" takes up variation by sudden temperature changes. Prevents crystallization.

Spring-and-Link Element
(for 5 amp. rating or less)

Fusing section secured to copper spring at middle of tube. Spring protects from vibration and crystallization.

Locked Cap Assembly
(patented)

Littelfuse process makes caps and tubes practically one-piece. No cement. Seals from moisture. Prevents cap loss.

FUSE EVERY INSTRUMENT AND ELECTRICAL CIRCUIT FOR SAFETY—WITH LITTELFUSES

Littelfuse Inc.

4757 Ravenswood Ave., Chicago, Illinois
260 Ong Street, El Monte, California

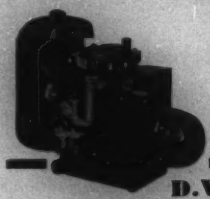
ONAN
ELECTRIC PLANTS

★ *Electricity for*
★ *Any Job—Anywhere!*

ONAN GASOLINE DRIVEN ELECTRIC PLANTS provide electricity in any location where it is not otherwise available, and for emergency and standby service.

Thousands of these reliable, sturdy plants are doing a winning job on all the fighting fronts by providing power and light for many vital war tasks.

Ratings from 350 to 35,000 watts. A.C. 50 to 800 cycles, 110 to 660 volts. D.C. 6 to 4000 volts. Also dual A.C. and D.C. output models. Air or water cooled engines.



Details gladly furnished on your present or post-war need for Electric Plants.

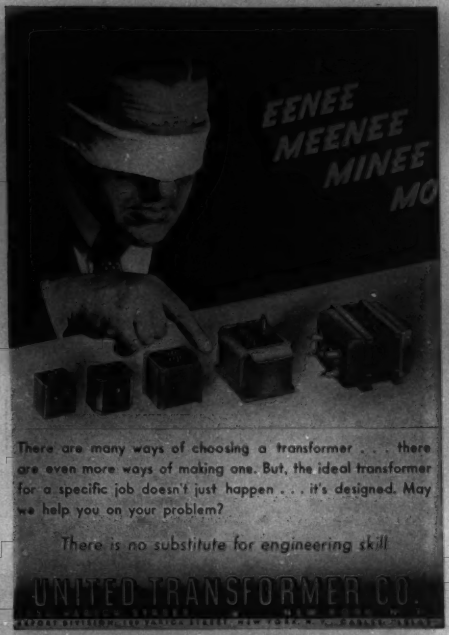
D. W. Onan & Sons
1931 Royalston Ave., Minneapolis, Minn.

Perfect INSULATING COMPOUNDS
for a wide range of temperature

In the Northern States, on the Gulf Coast, and both east and west—Minerallac Insulating Compounds are specified . . . proving that these materials do "stand up" no matter what change in temperature may arise.

• WRITE FOR BULLETIN 186 •

MINERALLAC ELECTRIC CO.
25 NORTH PEORIA ST. CHICAGO



There are many ways of choosing a transformer . . . there are even more ways of making one. But, the ideal transformer for a specific job doesn't just happen . . . it's designed. May we help you on your problem?

There is no substitute for engineering skill

UNITED TRANSFORMER CO.

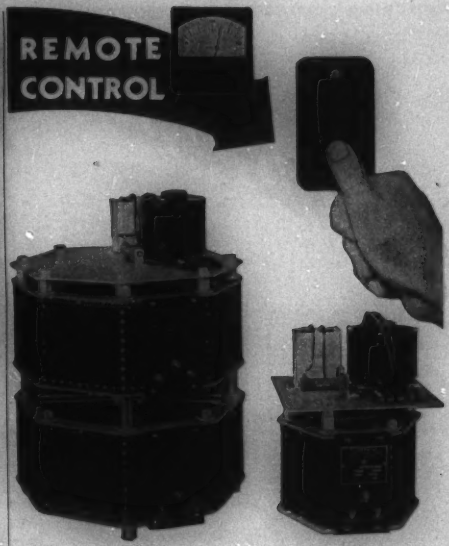
AMP
Diamond Grip
INSULATION SUPPORT TERMINALS
FOR WIRE SIZES 22 to 14 INCLUSIVE
PURE COPPER ELECTRO-TINNED
THREE PERFECT CRIMPS AT ONE TIME! No training period necessary for operators
POSITIVE "DIAMOND GRIP" INSULATION SUPPORT
22% lighter in weight 3/32nds of an inch shorter
PRECISION HAND DIE CRIMPING TOOL
Assures perfect mechanical and electrical connection. Self-gauging

Solderless TERMINALS with INSULATION SUPPORT

This engineered terminal is being used in great quantities by the Aircraft, Electronic, Electrical, and Marine Industries . . . Get the facts about saving MAN HOURS on your Solderless Wiring. All details are yours for the asking. Write today for Bulletin 19—The AMP System of Solderless Wiring.

AIRCRAFT-MARINE PRODUCTS INC.

Canadian Representatives: A & M Accessories Toronto, Ontario



Available in sizes up to 75 KVA

Large amounts of POWER can now be controlled by a push button or automatic device

Choose POWERSTAT MOTOR DRIVEN VARIABLE TRANSFORMERS for control. When regulation of voltage, current or power is nessesary in your design, POWERSTATS are the answer to your most rigid specifications. This equipment is an engineered combination of a POWERSTAT VARIABLE TRANSFORMER and a highly damped low speed motor of advanced design.

for

SMOOTH STEPLESS CONTROL

EXACTING CORRECTION

FREEDOM FROM OVERSHOOTING

ZERO WAVE FORM DISTORTION

CONNECTION TO AUTOMATIC OR PUSH BUTTON CONTROL STATIONS

GOOD REGULATION WHERE OUTPUT IS TO BE INDEPENDENT OF LOAD AND POWER FACTOR

SELECT

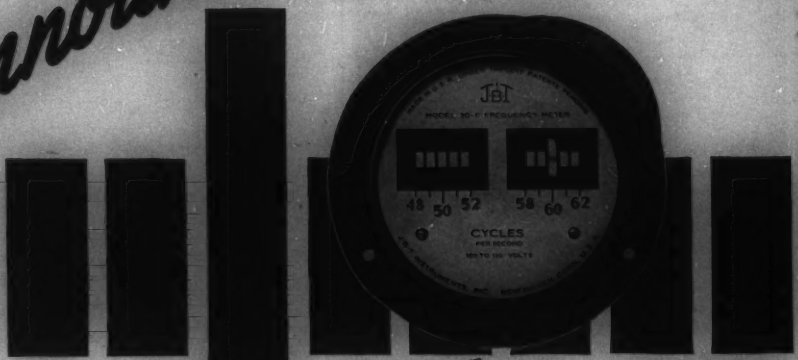
POWERSTAT MOTOR DRIVEN VARIABLE TRANSFORMERS

Send for POWERSTAT Bulletin No. 149 EE and Automatic Voltage Regulator Bulletin No. 163 EE.

SUPERIOR ELECTRIC CO.

71 LAUREL ST. BRISTOL, CONN.

Announcing A NEW LINE



VIBRATING REED FREQUENCY METERS

Sturdy and Simple in Design, Permanently Accurate

Important new features of this line are—simplified construction, with fewer parts—individual reed activation so that the whole bank does not vibrate—great variety of cases and sizes. Vibrating reed type of frequency meter offers these advantages:

- easy to read
- needs no adjustment in service
- low in power consumption
- exceptionally accurate
- not affected by wave form
- not affected by normal temperature change or external magnetic fields

Available in full range of frequencies—full range of types and sizes—full or half-cycle increments—sharp or broad response—wide voltage range.

{Manufactured under Triplett Patents and/or Patents Pending}

Bulletin VF-43 just off the press. Write for your copy now.

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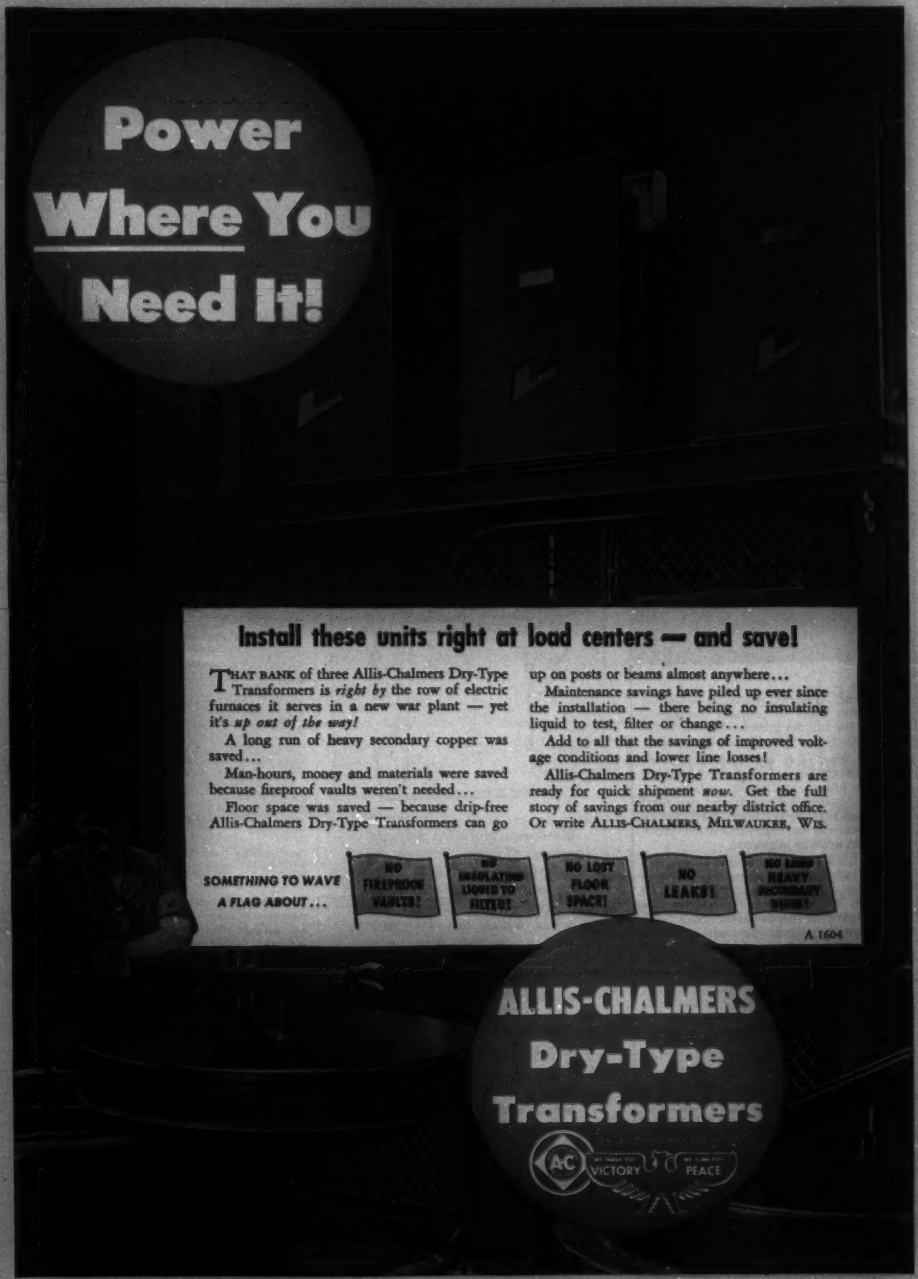
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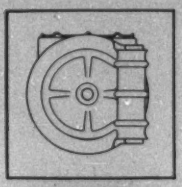

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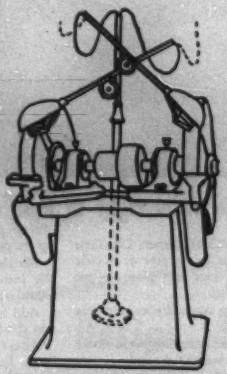

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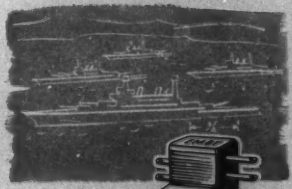

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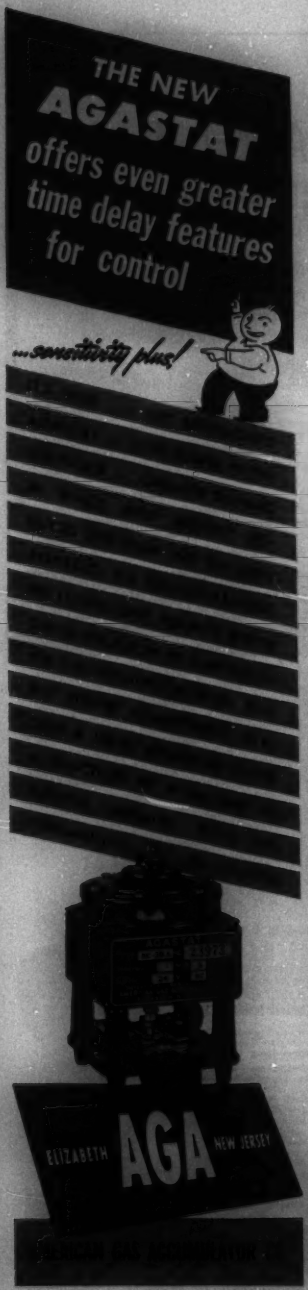

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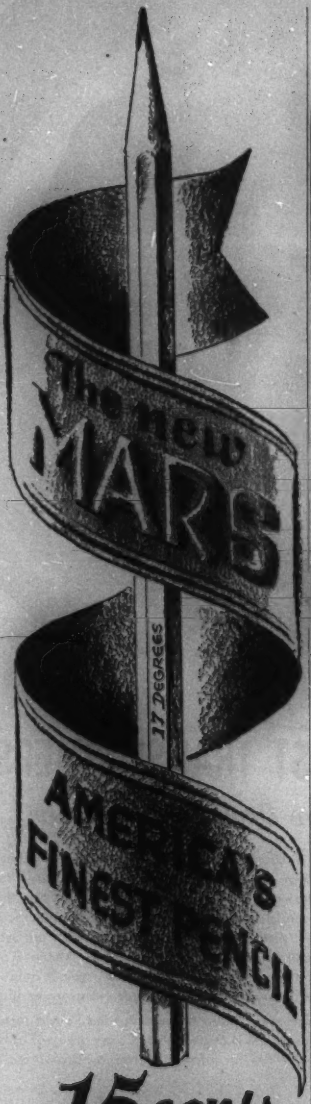

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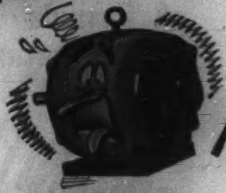

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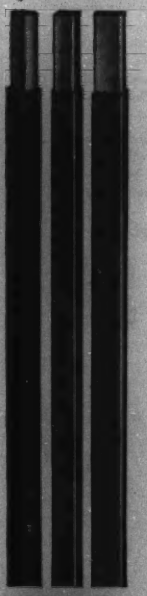

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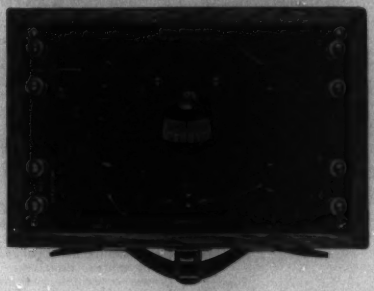

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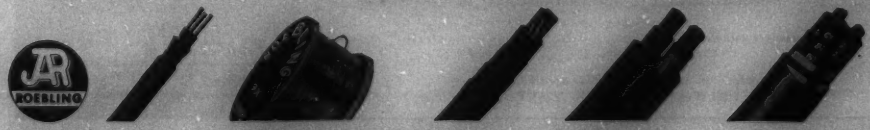

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In these days when the efficiency of America's power distribution is especially vital, many an unusual and specially designed transformer is going to work directly or indirectly for Uncle Sam. The 1,000 KVA Kuhlman transformer shown here is an example. It is a 3 phase, 60 cycle, OISC Transformer rated 13,800 Delta —480 Delta volts. • The box mounted on the low voltage side contains a 3-pole, 3-coil circuit breaker with time delay, trip shunt and over current trip coil. Rated 600 amperes. This unit is also equipped with a low-oil-level alarm, a conservator tank, a primary junction box with 3-1 conductor potheads and an alarm type thermometer in addition to all the other accessories usually built into a Kuhlman Power Transformer. Whether you need a special transformer or any other type of Power, C.S.P., Distribution or SAF-T-KUHL Transformer or line regulator it will pay you to get facts and prices from Kuhlman.

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